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ABSTRACT

These volumes are, respectively, the self-instructional student manual and the teacher manual that cover the fifth set of training topics in this course for television repair technicians. Both contain identical information on the television picture tube and its surrounding circuit, including sections on the principle of the picture tube, the basic structure and principles of the color picture tube, kinds of color CRTs (cathode ray tubes) and their general characteristics, surrounding parts of the color CRT, convergence, and the picture tube circuit. Circuit diagrams and line drawings are included. (CML)

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TV TROUBLE-SHOOTING MANUAL
VOLUMES 11-12

Part 5: Picture Tube and Its Surrounding Circuit
Student and Instructor's Manuals

Asian and Pacific Skill Development Programme
Islamabad, Pakistan

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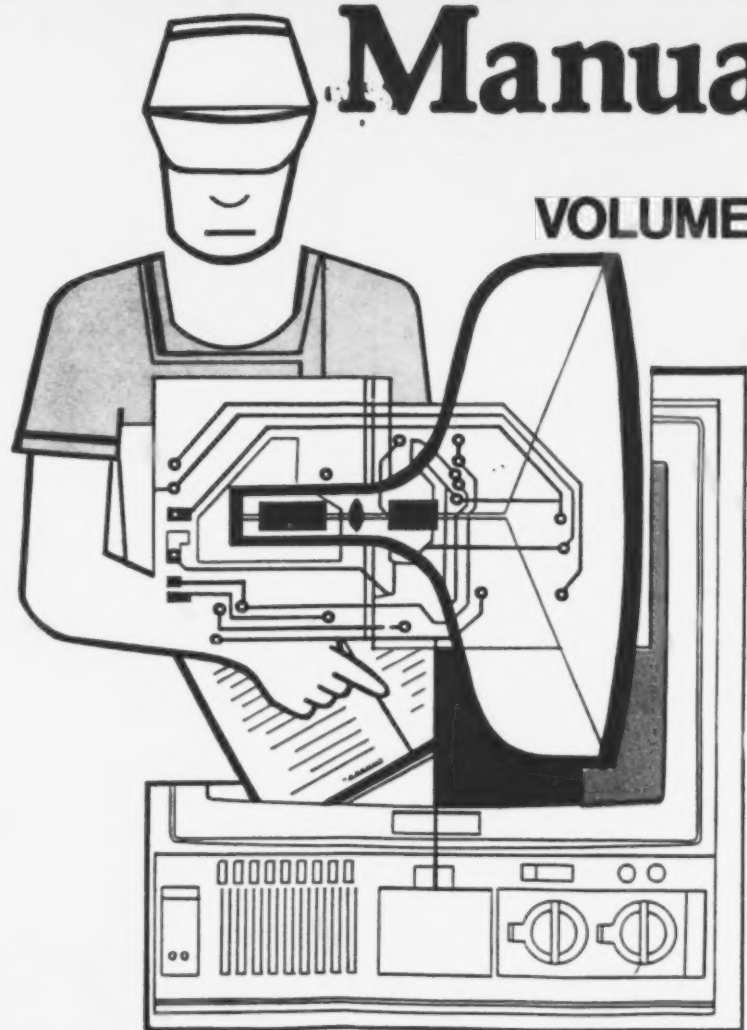
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TV Trouble-shooting Manual



BY MASAACKI MUKAI AND RYOZO KOBAYASHI

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TV Trouble-shooting Manual

VOLUME 11

BY MASA AKI MUKAI AND RYOZO KOBAYASHI

Part 5: Picture tube and its surrounding circuit



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INTERNATIONAL LABOUR OFFICE
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Part 5: Picture tube and its surrounding circuit

Principle of the picture tube (CRT)

The picture tube, or the cathode-ray tube (CRT), is the last stage in transforming video signals into pictures on the screen of TV receivers. The CRT consists of an electron gun and a phosphor screen in an air-evacuated, bell-shaped glass envelope. The electron gun produces the electron beam.

When the beam strikes the screen, the area bombarded by the electrons emits light. The electron beam is modulated and controlled by the video signal with the picture information needed to reproduce the original picture transmitted by the TV stations.

The details in TV picture reproduction will be discussed using the black-and-white CRT as an example.

Basic structure and function of a black-and-white CRT

The basic structure of a CRT is shown in Figure 5-1. The electron gun and the phosphor screen are in a high-vacuum bell-shaped glass envelope. The glass envelope consists of a narrow neck and a cone. The phosphor screen is the bottom of the cone, coated with phosphor material.

When the phosphor screen is hit by the electron beam, it emits light. The electron gun is in the neck of the CRT. It consists of the cathode and several cylindrical electrodes. The cathode radiates electrons, while the cylindrical electrodes perform other individual functions.

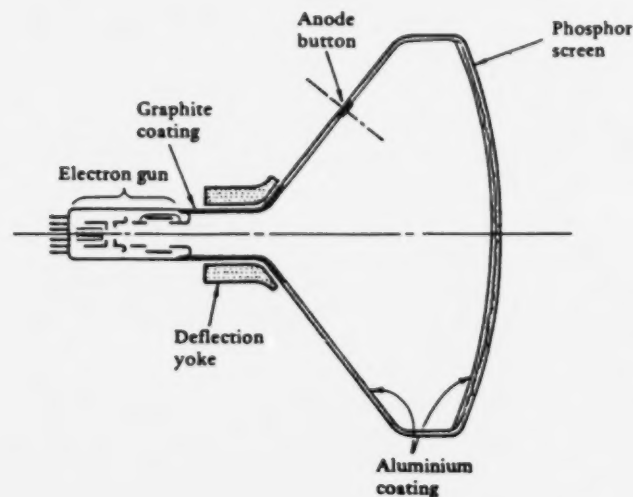


Figure 5-1
Basic structure of a CRT

The first electrode, called the control grid, concentrates and controls the amount of the electron beam that reaches the screen. The other electrodes are the accelerator grid and the focus grid. The accelerator grid speeds up the electrons towards the screen. The focus grid focuses and converges the electron beam to a small spot on the screen.

The last electrode (generally the fifth) is called the high-voltage anode. It is connected to a conductive graphite coating sprayed inside the wall of the CRT. This coating is also connected to the aluminium coating (metal back) of the phosphor screen.

Initially, the electrons emitted by the cathode are slow. These slow-moving electrons are speeded up by the accelerator grid.

The final speed of the electrons depends on the accelerator voltage applied to the high-voltage anode. If the anode voltage is 10 kV, for example, the final speed of the electrons hitting the screen will be around 60,000 km/sec.

The electron beam travels with constant speed after passing through the high-voltage anode.

To sum up: the electron gun performs several functions. It first produces the electron beam. The control grid controls the amount of the beam, the accelerator grid speeds it up and the focus grid converges it to the smallest possible spot on the screen.

The electron beam has to produce a raster. A raster is the rectangular area scanned by the beam as it is deflected horizontally and vertically. The beam is turned aside electromagnetically by the deflection coils mounted outside the neck of the CRT. These coils are called the yoke.

Sawtooth currents are supplied to the deflection coils, producing a varying electromagnetic field that deflects the beam horizontally and vertically.

The electron gun and the electron beam

Figure 5-2 illustrates a typical electron gun. Note that the cylindrical metallic electrodes are arranged in series on one axis.

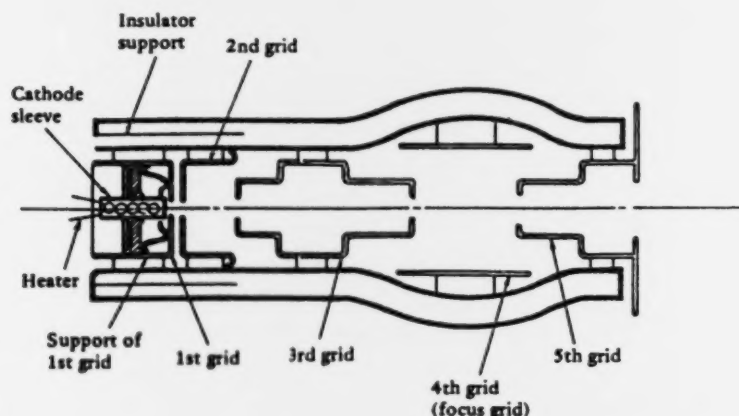


Figure 5-2
A typical electron gun

The major parameters that determine the operation of the CRT are the a) length of the electron gun, b) the diameter of the cylindrical electrode, c) the distances between electrodes and d) the voltages of individual electrodes.

The cylindrical electrodes are referred to in terms of their position relative to the cathode. This means that G1 is the electrode nearest the cathode, G2 the second nearest and so on.

Emission of electrons from the cathode. The cathode is coated with a special substance consisting mainly of barium oxide, designed to emit electrons when heated to around 800 degrees centigrade. (See Figure 5-3.)

Modulating the electron beam. The bias voltage of the CRT is the voltage between the cathode and the control grid (G1). The amount of electrons emitted by the cathode is controlled by the bias voltage.

The bias voltage can be increased by raising the G1 voltage (G1 voltage becomes more negative) while keeping the cathode voltage constant, or by increasing the cathode voltage (cathode voltage becomes more positive) while keeping the G1 voltage constant.

By varying the bias voltage, one controls the amount of emitted electrons. As the bias voltage is increased, the control grid allows less electron flow because electrons carry negative charges which are repelled by the negative voltage of G1. For the same reason, the control grid allows greater electron flow as the bias voltage is decreased.

In this discussion, the cathode is set as the reference voltage. Hence when we say that the G1 voltage is "negative," the actual voltage of G1 is less than the actual voltage of the cathode both with respect to ground.

Generally the brightness of the phosphor screen is proportional to the intensity of electron beam. Since the bias voltage can control the amount of electrons emitted from the cathode, this bias voltage can control the brightness of the phosphor screen. Hence the amount of the electron beam is varied by changing the video signal applied to G1 or the cathode. This process is called *modulating the electron beam*.

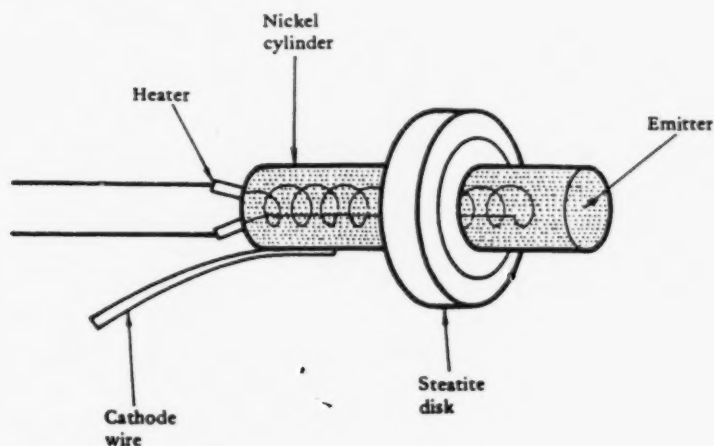


Figure 5-3
Heater and cathode assembly

If the video signal is applied to the cathode, the modulation of the beam is called the cathode drive. If the video signal is applied to the control grid, it is called the grid drive.

In the grid drive the G1 voltage changes only with respect to the cathode. In the cathode drive the voltage of the cathode varies. Since the cathode is the reference voltage of the electrodes, the individual voltages of each electrode are affected. The cathode drive is commonly used in modern television receivers.

The amount of electron emission is significantly controlled by the voltage drop between the cathode and G1 (the bias voltage). Nevertheless the voltage at G2 and G3 both relative to the cathode also affect the amount of the electrons emitted.

General characteristics of a CRT

The electrical characteristics of a CRT depend mainly on the characteristics of the electron gun. These characteristics will be taken up in the following discussion.

Cut-off voltage. When the bias voltage is increased, the amount of the electron beam becomes less. The value of the bias voltage such that no electrons strike the phosphor screen (no visible raster) is called the cut-off voltage. This cut-off voltage is denoted by E_{co} .

There are two ways of measuring the cut-off voltage. One is to set the cathode voltage as the reference voltage and adjust the G1 voltage such that the raster is barely visible. The voltage is then measured at G1 with respect to the cathode. This voltage is negative and is called the grid cut-off voltage (E_{c1co}). Another is to set the G1 voltage as the reference voltage and adjust the cathode voltage until the same condition is satisfied. The cut-off voltage is then measured at the cathode with respect to G1. This voltage is positive and is called the cathode cut-off voltage (E_{kco}).

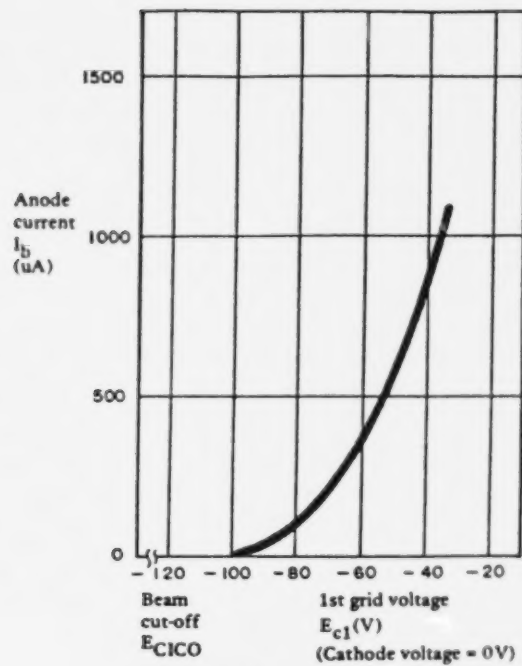
Generally the cut-off voltage lies between -30 and -80 V for black-and-white CRTs and between -50 and -100 V for colour CRTs. This value is measured at G1 with respect to the cathode. The value of the cut-off voltage usually differs even among CRTs of the same size, type and brand. Increasing G2 voltage (E_{c2}) raises the cut-off voltage.

Cathode emission. The intensity of the electron beam produced by the electron gun depends on the structure, shape, size and substance used for the cathode.

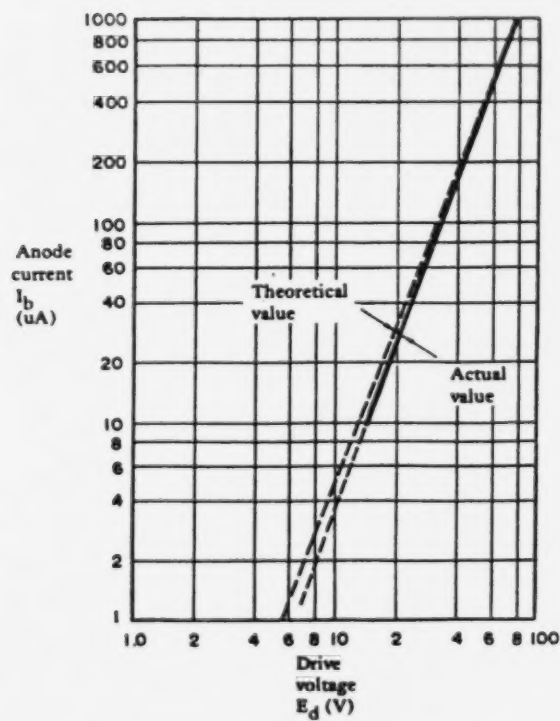
The ability of the cathode to emit electrons is called *perveance*. For CRTs with the same cut-off voltage, a CRT with a greater perveance produces an intense electron beam. Thus a smaller driving voltage is required.

With this kind of electron gun, the G2 voltage (E_{c2}) can be lower, ranging from 40 to 100 V, than the usual values of about 400 V. This high-perveance gun is used especially in CRTs of cathode-drive TVs and in small CRTs of small screen solid-state TVs.

Current characteristic and gamma. The relationship of the bias voltage and electron beam current is shown in Figure 5-4(a). Plotted on the horizontal axis is the drive voltage E_d . E_d is the variation of the G1 voltage from the cut-off voltage (E_{co}) towards a value such that the beam current increases.



(a) Current characteristic for (19") CRT



(b) Drive characteristic

Figure 5-4
Characteristics of a CRT

The relationship between E_d and I_b is called the *drive characteristic*. The graph in Figure 5-4(b) is expressed in logarithmic scales to illustrate this relationship clearly. The slope of the curve in Figure 5-4(b) is called *gamma*. When getting the value of the cut-off voltage in a dark room, gamma for a 20-inch colour CRT is around 2.5 to 3.

Focus. 1) Methods of focusing the electron beam. One must focus the electron beam to converge it to the smallest possible spot on the phosphor screen. Figures 5-5(a) and (b) show the arrangement of the electrodes of the electron gun and the electron beam, respectively. In (b) the electron beam is initially focused by an electromagnetic field near the electrodes. This field converges the beam to a point near G1 and G2. This point is called the *cross-over point*.

Since electrons repel each other, the beam diverges as it travels away from the cross-over point. Therefore the electron beam must be focused again and the need for a main convergence lens arises. This lens is an electronic lens that converges the electron beam on the phosphor screen. Its function is similar to an optical lens used to focus light rays.

There are two types of main convergence lenses: static and dynamic.

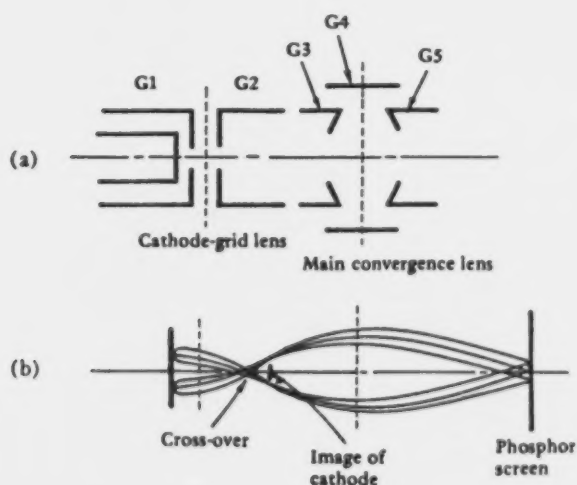


Figure 5-5
Electronic lens and beam convergence

The static convergence lens is a cylindrical electrode. The beam is focused by the electric field produced by the voltage applied to the cylindrical electrode. The dynamic convergence lens is a permanent magnet or a convergence coil mounted outside the neck of the CRT. The beam is focused by the magnetic or electromagnetic field produced by the magnet or the convergence coil. Black-and-white TV sets normally use the static convergence lens.

There are two kinds of electron lenses in the static convergence system. One is the uni-potential lens, the other the bi-potential lens as shown in Figure 5-6. Table 5-1 compares the characteristics of these two kinds of lenses. The uni-potential lens is used in black-and-white and small colour CRTs; the bi-potential lens, in medium 18-inch and big colour CRTs.

Table 5-1
Comparison of static lens

Type Item	Uni-potential	Bi-potential
Focus voltage	-100 to 400V	around 5kV
Size of focused spot on screen	large	small
Changes of focus on different scenery	small	large
Focus on the corners of screen	small	large
Focus voltage	+B voltage	High voltage used in horizontal deflection circuit

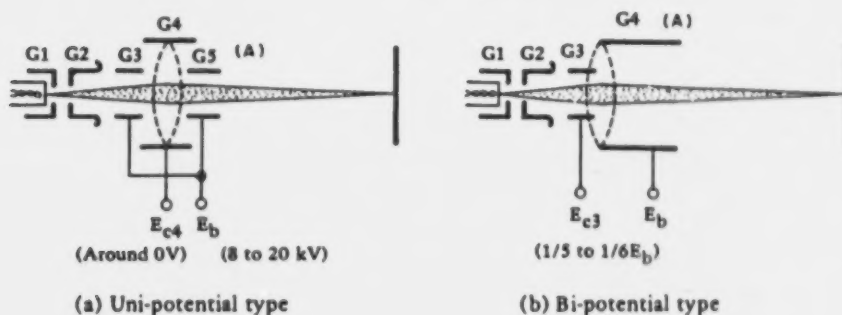


Figure 5-6
Static beam convergence

2) Focus characteristic of the CRT (sharpness and resolution). The focus characteristic of a CRT is generally evaluated by the clear distinction (resolution) of each line in the wedge pattern of a standard test. However, this alone is not a complete evaluation.

Usually, even though the resolution of the lines is good, the sharpness of the lines is poor. That is, the lines are not well focused. Poor sharpness results in poor contrast, evident in the smaller elements of the picture. The effect of this high-resolution, low-sharpness quality is demonstrated using the dot patterns on the screen. Careful observation will reveal a halo around the dots. This halo is usually generated by a defective electronic lens (aberration of the lens) or by a lower than normal voltage applied to the lens.

The halo effect is shown in Figure 5-7(b). Figure 5-7(a) shows the ideal dot and Figure 5-7(c) shows an expanded dot. The expanded dot is caused by a higher than normal voltage applied at the electronic lens.



Figure 5-7
A faceplate dot lighting

The phosphor screen

The screen is a thin coating of fine phosphor crystals that emit light when hit by electrons. A very thin coating of aluminium is also applied to the phosphor screen. This coating is called the *metal back*.

Phosphor screen materials. The phosphor substance consists of very fine crystal particles that emit light when bombarded by high-velocity electrons.

The diameter of these particles is a few microns (a micron is one millionth of a metre). There are many types of substances developed for the phosphor screen.

For colour CRTs, different substances are used. For the red phosphor, rare earth elements such as yttrium and europium are used. Zinc sulfide, mixed with a small amount of silver, is usually used for the blue phosphor; a mixed sulfide of copper and aluminium is used for the green phosphor. The white phosphor of the black-and-white CRTs is an even mixture of the blue phosphor and the yellow phosphor (which is a mixed sulfide with a small amount of silver).

Metal back (aluminised screen). As shown in Figure 5-8, the phosphor screen is covered with a fine aluminium coating called the *metal back*. This metal back is connected to the high-voltage anode of the CRT. Its thickness is usually between 0.1 and 0.3 microns. Since it is so thin and the electrons so small, the electron beam can easily penetrate it.

The metal back has the following advantages.

- 1) It eliminates voltage drop between the screen and the anode.

Electrically, the phosphor screen is an insulator. When electrons hit the phosphor screen, negatively charged electrons pile up on the screen and create a negative space charge. This charge will repel or slow down the electron beam. In effect, the brightness of the screen does not increase the anode voltage.

But if the metal back is included, the electrons accumulated on the screen are absorbed by the metal back because the anode is connected to it through the graphite coating called the aquadag. Thus there will be no voltage drop between the anode and the screen, because the metal back is shorted to the anode by the aquadag.

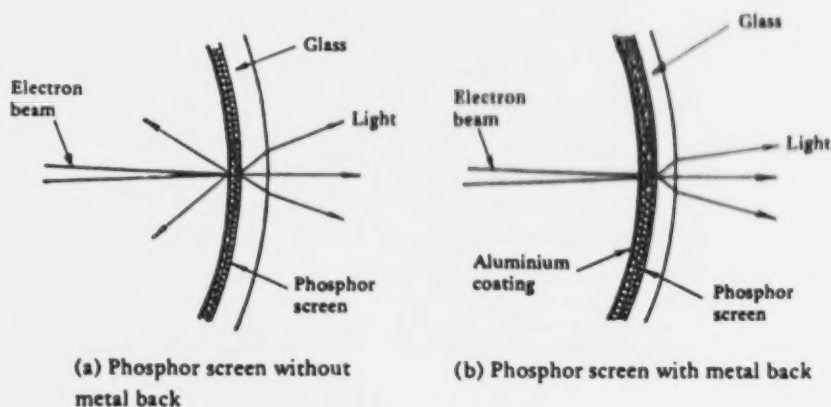


Figure 5-8
Metal-back screen

2) It doubles the brightness.

When the phosphor is hit by the electron beam, it emits light towards both the faceplate and the electron gun. With the metal back attached, light emitted towards the electron gun is reflected towards the faceplate. Therefore the brightness is increased by around 100 per cent.

3) It prevents ion spots.

Even though the CRT is a high-vacuum tube, some gas particles remain inside the tube and are ionised by the electron beam. The resulting ions accelerate towards the screen. They have low velocity and are heavy so they are not turned aside by the deflection coils and travel straight towards the centre of the screen.

If these ions are allowed to hit the screen continuously, the phosphor coating will be damaged. The ions burn the screen and the burned spot is called an *ion spot*. This spot is dark grey and becomes permanent. However, the ions are much bigger than the electrons so they cannot penetrate the metal back as the electrons can. Thus the metal back prevents ion spots.

Characteristic of light emission. The brightness of the phosphor screen depends on the anode voltage, beam current, screen size, glass-plate transparency and the ability of the phosphor to emit light.

As shown by the graph in Figure 5-9, the brightness is proportional to the value of the electron beam current. But the brightness can saturate at higher currents. When the brightness is saturated, it will not account for any further increase in the beam current.

Another important light-emission characteristic of the phosphor screen is its persistence. After being hit by electrons, the phosphor screen emits light. This light gradually fades or fluoresces after a short time. If this fluorescent effect takes place within a considerable period, the screen will show a trailing or smeared picture.

Persistence is the time it takes the phosphor to fade to one tenth of its original brightness.

The widely used phosphor sulfide in black-and-white CRTs and the green and blue phosphor of the colour CRTs have a persistence time of between 30

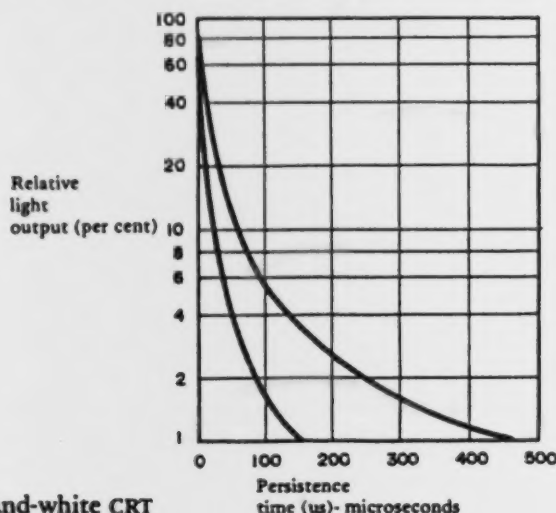


Figure 5-9
Persistence of a black-and-white CRT

and 100 microseconds. The rare earth elements used for the red phosphor of the colour CRT have a persistence time of approximately 1 millisecond. This long persistence poses no problem in practical applications.

Contrast and the transparency of the faceplate. The quality of the picture depends on the contrast ratio. The contrast ratio is the ratio of the brightness of the bright peak, or white-level luminescence, to the brightness of the dark peak, or black-level luminescence. The contrast ratio should be at least 20:1. However, a ratio of 30:1 or greater is desirable for a better picture.

In usual viewing conditions (watching TV in a bright room), the surface of the CRT screen reflects external room light. This light mixes with the light emitted by the phosphor screen; thus the portion of the screen which should be black does not appear as dark as it should. This lessens the darkness or increases the black-level luminescence, causing a smaller contrast ratio.

If, for example, the brightness of the white-level and the black-level luminescence is 45 ft-L and 1 ft-L, respectively, without external light reflection, the contrast ratio will be 45:1. But if we consider the reflection of external room light and assume it to be 3 ft-L, the resulting contrast ratio will only be 15:1. The decrease in contrast ratio because of external room light can be compensated by placing a filter on the faceplate of the screen.

Let us analyse what happens when a filter, say with 50 per cent transparency, is placed on the faceplate. This filter will reduce the brightness of the white-level luminescence by 50 per cent making it 22.5 ft-L.

Consider the effect of this filter on the reflected room light. Before the external room light reaches the surface of the faceplate, it is reduced by the filter to 50 per cent making it 1.5 ft-L. After it is reflected by the faceplate, the reflected room light is again reduced by the filter to 50 per cent, making the final value of the external room light 0.75 ft-L.

When we take the ratio of the white-level luminescence to the black-level luminescence, 22.5 ft-L over 0.75 ft-L, the contrast ratio improves from 15:1 to 30:1. Thus although the filter reduces the brightness of the screen, the contrast ratio improves.

The faceplate of black-and-white CRTs is a dark tinted glass; the faceplate of colour CRTs is a clear glass with 85 per cent transparency. A clear glass is used for colour CRTs because its contrast ratio is improved by the black-matrix phosphor screen.

The life span of the CRT and some technical details

The life span of the CRT. The life span of the CRT is approximately 10,000 hours. Assuming that the TV set is used for about 2,000 hours a year (a normal average of approximately five hours a day), then the life span of the CRT is practically around five years. The principal factor which determines the life span of the CRT is the ageing of the cathode, which is caused by the remaining gas particles inside the CRT.

A chemical reaction occurs between the coating of the cathode and the ions produced when these gas particles are ionised by the electron beam. This reaction corrodes or ages the cathode. The ageing of the cathode decreases its efficiency in electron emission. A decrease in electron emission causes a raster

and a picture that cannot be made bright enough.

A typical symptom of ageing is the considerable time it takes for the CRT to warm up. The weak electron emission of the cathode can be temporarily remedied by increasing the heater or filament voltage. A small, multi-tapped filament transformer is used to increase the heater voltage, but this is difficult to do with TVs without power transformers.

Increasing the filament voltage also shortens the life span of the cathode. An excessive increase in the filament voltage causes blooming in the picture. Thus the only practical remedy for weak electron emission is to change the CRT.

Implosion protection. Since the CRT is a high-vacuum tube and has a large surface area, the force exerted on it by the atmospheric pressure is great. Hence, because of its inherent structure, there exists a danger of implosion (inward explosion). When a CRT implodes, the glass envelope shatters and its fragments are sucked inwards because of the negative pressure inside the CRT. After imploding the tube explodes.

In the past, a thick safety glass (about 10 mm) was placed in front of the CRT screen to protect the viewer from implosion. But this has its drawbacks. The safety glass reflects external light decreasing the contrast ratio. It also increases the weight of the CRT.

Furthermore, fine dust particles accumulate between the CRT screen and the safety glass and these are very difficult to remove. For these reasons, modern CRTs use a mechanical support to minimise the danger of implosion.

CRTs with integral-implosion protection features are called *implosion-proof CRTs*. There are two types of implosion protection used: the tension-belt type and bonded type. (See Figure 5-10.)

X-rays in colour CRTs. X-rays are generated whenever high-velocity electrons hit metals. When the anode voltage is high enough (greater than 16 V), X-rays are generated when high-velocity electrons strike the metal shadow mask. The amount of X-rays is proportional to the value of the anode voltage of the electron gun. Hence a special glass bulb which absorbs X-rays is used for big colour CRTs.

All TV receivers are designed to meet the international safety standard which limits the level of X-rays to less than 0.5 milli-Roentgen per hour (mR/hr) measured five centimetres away from any surface of the receiver.

The classification and coding of picture tubes

Cathode-ray tubes commonly used in TV sets have a rectangular screen. In black-and-white CRTs the diagonal of its screen measures from 2 to 23 inches; for colour CRTs, from 5 to 26 inches.

Characteristics of black-and-white CRTs. Except for the small CRTs (i.e. tubes with screen diagonal less than 10 inches), the deflection angles are usually 110 or 114 degrees. Dark tinted glass plates are commonly used for the faceplate.

The diameter of the neck is around 29 mm for bigger CRTs; 20 mm for medium and small CRTs. Protection from integral implosion is ensured.

Characteristics of colour CRTs. The deflection angle is usually 90 or 110 degrees. (Some colour CRTs use 114 degrees.)

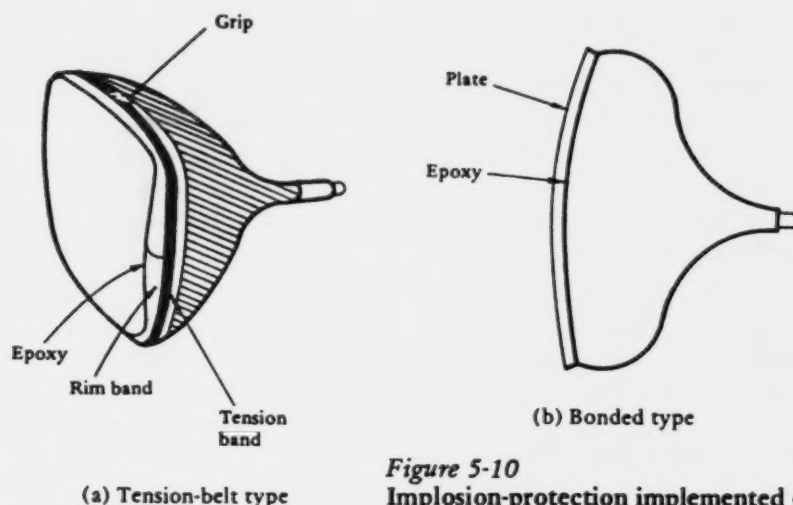


Figure 5-10
Implosion-protection implemented CRTs

A clear glass plate (85 per cent transparency) is used for the faceplate of the black matrix TV screen. The diameter of the neck is from 29mm to 36.5mm. Protection from integral implosion is ensured.

Short CRTs use wide-angle deflection and longer CRTs use small-angle deflection because the electrons in longer tubes have more time to be deflected than the electrons in the shorter tubes.

A large deflection angle can be obtained by supplying more power to the deflection circuit. CRTs with large deflection-angles have a smaller neck diameter so that the deflection coils can be placed as close as possible to the electron beam. This enables a stronger magnetic field to act on the electron beam.

For 20-inch colour CRTs the effective area of the screen is 30cm by 40 cm. The length for CRTs using a 90-degree deflection angle is around 44 cm; for CRTs using a 110-degree deflection angle it is around 37 inches.

The classification of CRTs registered under the Japan Electronics Industries Association is shown in Table 8-2. Note that the CRTs are categorised according to their bulb size (diagonal length of the screen), their registration number and the phosphor material used.

Table 8-2
Classification of CRTs

	Unit used for measuring CRT faceplate diagonal	Registration code	Phosphor
Japanese	mm	alphabetical	Black-and-white B4 Colour B22
American	inches	alphabetical	Black-and-white P4 Colour P22

Example:

Japanese

310GNB4 (12 inches B/W CRT)
310GNB4A (Modified version of 310GNB4)
510DXB22 (20 inches colour CRT)

American

19GYP22

Basic structure and principles of the colour picture tube

The principal structure and function of a shadow-mask colour CRT

There are several designs of colour picture tubes. Figure 5-11 shows three.

There are three patterns in the printing of the phosphor screen: dotted, vertical-slotted and vertical-striped. For each pattern are different shadow masks. These shadow masks have holes of different shapes: round, slotted and vertical-striped.

Sony Trinitron colour CRTs use the striped pattern for the phosphor screen printing and, consequently, the shadow mask with vertical-striped holes. This shadow mask is called the aperture grille. Although these shadow masks differ in the shape of their holes, they have the same function. Therefore we will refer to any of them as a shadow mask.

The shadow mask is a thin metal plate (about 0.15 mm) mounted inside the colour CRT 10 mm away from the phosphor screen. It contains 200,000 to 400,000 tiny round holes arranged in rows (500 to 200 vertical-striped holes for aperture grilles.)

Each hole has a diameter of 0.20 to 0.25 mm. These holes are evenly spaced with a distance of 0.56 to 0.75 mm. For each hole in a shadow mask, there is a corresponding trio of red, green and blue phosphor dots. Only 15 to 20 per cent of the electron beam passes through the mask.

There are two types of electron gun arrangements in a colour CRT: the delta gun and the in-line gun. Figure 5-11(a) shows the delta gun arrangement. The three guns are positioned to form the vertex of an equilateral triangle.

In the in-line arrangement, shown in (b) and (c), the electron guns are placed side by side in a horizontal or a vertical plane. The horizontal arrangement of the in-line gun is more widely used.

The three electron beams radiated by the three electron guns are turned aside by the deflection coils to scan the phosphor screen. But these beams are blocked by the shadow mask.

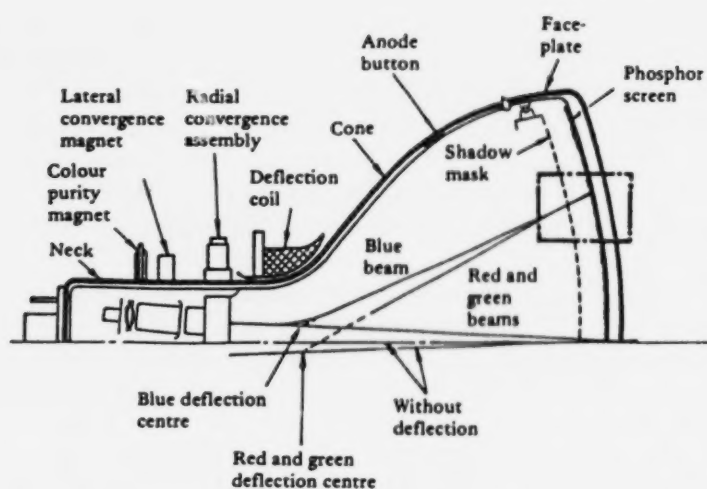
The phosphor screen emits light only when it is hit by electrons that pass through the holes of the shadow mask. The beams should hit only their corresponding colour phosphor dot or stripe. Therefore the colour CRT should be so designed that the deflection centre of each electron beam (see Figure 5-12), the centre of every individual hole and its corresponding phosphor dot or stripe from points in a single imaginary straight line.

As the electron beam is modulated by the luminance and the chroma signal, every set of phosphor dots (red, green and blue) will emit red, green and blue lights according to the colour information in the chroma signal for the reproduction of almost all colours.

Production of three primary colours and colour purity

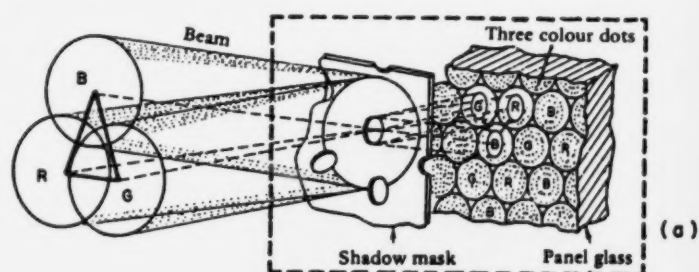
The colour CRT screen is formed by roughly one million sets of red, green and blue phosphor dots. This immense number of closely, yet evenly spaced, phosphor dots on the screen is possible because of high printing technology.

In filling the screen with these dots, it was assumed that the paths of the

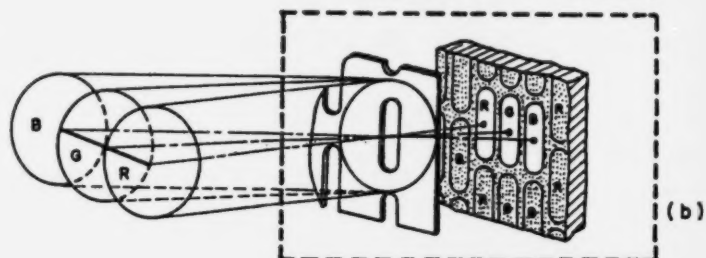


The following figures are the magnification of the square area shown in the above figure.

(a) Round shadow mask and phosphor screen in delta gun



(b) Slotted shadow mask and phosphor screen in in-line gun



(c) Aperture grille-shaped shadow mask and phosphor screen

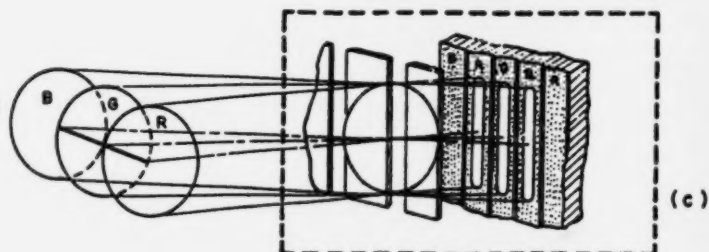


Figure 5-11
Structure of a shadow-mask colour CRT

deflected electron beams were similar to the paths of the light rays from a spotlight placed in the deflection centre of the electron beams, while the phosphor material for each colour is developed or applied to the screen.

In setting the phosphor material for the red electron beam, the screen is first evenly coated with red phosphor mixed with other chemicals that make it insoluble in water after exposure to light. Then the shadow is set in place and a spotlight is placed at the deflection centre of the red electron beam. The light is turned on and the part of the phosphor coating uncovered by the holes of the shadow mask is exposed to light.

After exposure, the shadow mask is removed and the screen immersed in water. The exposed part of the coating remains on the screen while the rest is dissolved. Since the spotlight was placed in the deflection centre of the red electron beam, the remaining phosphor material on the screen is the phosphor dots or stripes for the beam. Thus it is assumed that this beam will only hit this phosphor material. The same principle is used in developing or printing the blue and green phosphors on the colour CRT.

The phosphor dots on the screen are very close to each other, making the design of the shadow mask very critical. The distance between the holes of the shadow mask, the distance between the shadow mask and the phosphor screen, and the radius of the curvature of the shadow mask should be precise. Also, the electron guns should be so arranged that the deflection centre of each beam will coincide with the spotlight used for developing the phosphor for each particular beam. This is necessary to enable the beams to hit only their respective phosphor material. The beams must also converge at the shadow-mask holes.

Because of the complicated manufacture of CRTs, it is very difficult to produce CRTs with precision. To compensate for the slight errors in manufacture, several adjustment mechanisms and accessories are included and they are discussed in the following sections.

Colour purity adjustment. This adjustment is necessary to make the three electron beams (R, G and B) hit only their respective phosphors so that reasonably pure red, green and blue rasters may be produced. In conventional TVs this can be done by sliding the deflection yoke along the neck of the CRT and/or adjusting the colour purity magnets (also called the beam landing magnets) that slightly bend the path of the electron beams.

Good colour purity is indicated by pure or solid red, green and blue rasters. Poor purity is indicated by colour patches usually at the corners of the screen.

Deflection yoke. In modern in-line colour CRTs the deflection yoke, together with several adjustment magnets which are adjusted with precision during the production stage, is mounted permanently on the neck of the CRT to avoid changes in its characteristic because of vibrations during transport. In this way the deflection yoke, the adjustment magnets and the CRT are considered one whole component.

Degaussing coil. Another important factor that affects colour purity is the presence of external magnetic fields such as the earth's magnetic field. This field is relatively strong enough to affect the path traversed by the electron beams to the CRT screen.

To minimise or counteract the effect of external magnetic fields, one gen-

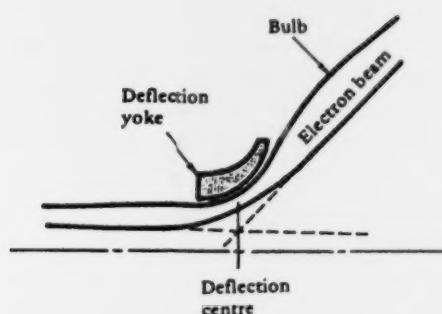


Figure 5-12
Deflection centre

erally attaches a steel cover to the cone of the CRT to shield external magnetic fields. However, the shadow mask of the colour CRT is magnetised by the earth's magnetic field. The degaussing coil is used to demagnetise the mask. In degaussing a TV receiver, one applies a decaying AC current to the degaussing coil. In the process, the decaying current produces a strong decaying magnetic field that demagnetises the shadow mask.

The principle of convergence

Occasionally, in multi-colour printing as in colour magazines, when two or more objects or parts of an image have different colours, the edges or borders of their colours overlap. This results in poor colour print.

When the beams do not hit their respective phosphor dots in colour CRTs, colour fringing occurs at the edges of the objects or parts of an object with different colours in the picture. This can be prevented by letting the three electron beams intersect in every hole of the shadow mask. The intersection of the three electron beams is called *beam convergence* or, simply, *convergence*.

One gets good colour reproduction if the three electron beams converge in every hole of the shadow mask.

There are two types of convergence: static and dynamic. Static convergence is the intersection of the three electron beams before they are turned aside by the deflection coils. Dynamic convergence is the intersection of the three electron beams while they are turned aside by the deflection coils. Improper static convergence causes an even degree of colour fringing all over the screen. This is caused by the misalignment of the three electron guns during manufacturing. This can be compensated by adjusting the static convergence.

In improper dynamic convergence the degree of colour fringing varies at different parts of the screen. The fringes are more pronounced at the edges, particularly at the corners of the screen, because even if the three electron beams are converged in the centre of the screen, the electron beams slightly diverge from each other when they are deflected, as shown in Figure 5-13.

Colour fringing is slightly compensated by the precise windings of the deflection coils.

In the delta gun assembly no matter how precise the windings of the coils, colour fringing is not totally eliminated. Thus the need for dynamic convergence. However, the coils are wound in such a way that adjusting the dynamic convergence becomes easier.

In the in-line gun assembly a precisely wound coil adjusts the static convergence. Thus, adjusting the static convergence is not necessary.

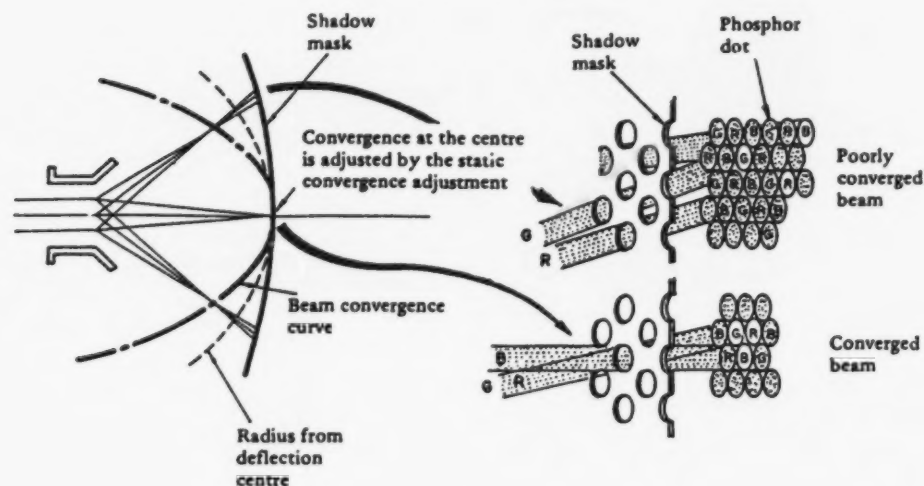


Figure 5-13
Poor convergence at the edge of the screen

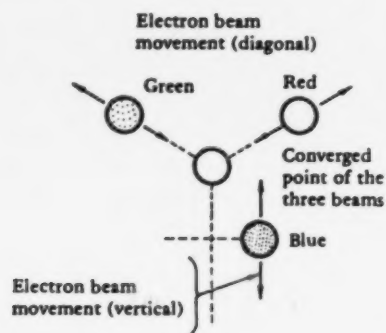
In the static convergence of the delta gun, the radial convergence adjustment deflects the electron beams radially from the centre [see Figure 5-14(a)] and the lateral convergence adjustment moves the electron beams sideways (in most cases only the blue beam is able to move sideways).

Dynamic convergence adjustment is usually done only by radial convergence adjustment. For the in-line gun, the convergence adjustment is done by changing the direction of the beams laterally, as shown in Figure 5-15.

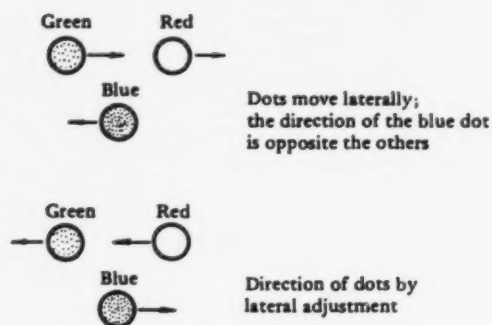
Production of colours on the phosphor screen and white balance

As described earlier, the phosphor dots or stripes on the screen are very small. It is hard to identify the individual coloured lights emitted by each coloured phosphor. What the eye sees as a multi-coloured picture is actually composite colour with discrete red, blue and green components. Almost all colours can be reproduced by controlling the intensity of the three electron beams to yield the proper proportion of the three primary colours, which are red, green and blue.

At TV broadcast stations the colour of the object is separated into its three primary colours by an optical filter inside the camera. The red, blue and green chroma signals are produced in proportion to the object's colour. Colour TV receivers have to reproduce the chroma signals properly.



(a) Radial convergence adjustment



(b) Lateral convergence adjustment

Figure 5-14
Colour dots movement of delta gun

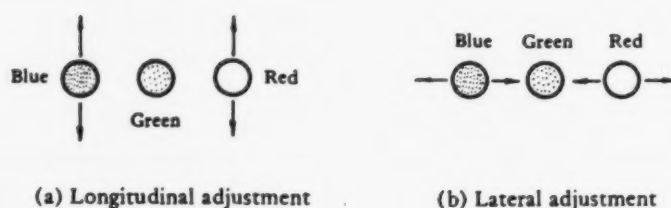


Figure 5-15
Beam convergence of in-line gun

When the standard white signal is transmitted by the TV station, the TV receiver should be adjusted to reproduce the same signal at all levels of brightness and contrast. This is called *white-balance adjustment*.

The ratio of the three electron beams to produce a standard white signal, one of the most important standards in the production of colour CRTs, is determined by the colour tone and light emission efficiency of the phosphors and the definition of the standard white.

The standard white of the NTSC (National Television Standard Committee) transmission is the white colour produced by sunlight (colour temperature roughly around 6500°K). Therefore the standard white of the colour CRT at the time of adjustment of the white balance should be set to the white colour produced by the sun. Nevertheless, considering human colour preference, the standard white used at the colour CRT is set at a little higher colour temperature (bluish white at about 9300°K). Hence the beam current ratio shown in specifications of the picture will produce a white raster with this colour temperature.

PICTURE TUBE AND ITS SURROUNDING CIRCUIT 45

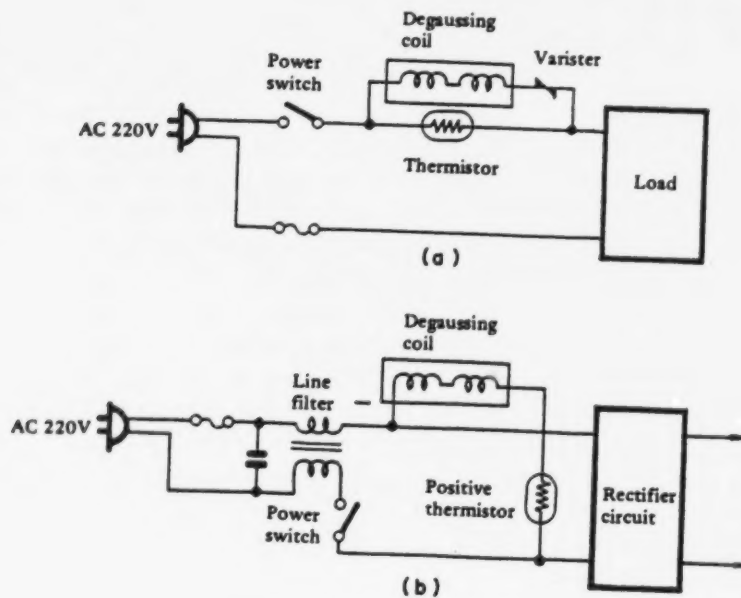


Figure 5-46
An automatic degaussing circuit

Kinds of colour CRT and their general characteristics

Structure of electron guns

The basic structure of electron guns in colour CRTs is similar to the guns in black-and-white CRTs. This is shown in Figures 5-2 and 5-6. The colour CRT, however, contains three electron guns.

In designing the electron guns for colour picture tubes, one always considers the simplicity of the structure and the efficiency of electron emission. The electron gun structure should be as simple as possible to fit in the small space allotted in the neck of the CRT.

But its effectiveness in radiating the electron beam should not be sacrificed. Figure 5-16 shows four types of in-line electron gun structures. The simplest consists of three independent electron guns, as shown in Figure 5-16(a). Each electron gun has its own cylindrical cathode and separate electrodes G1, G2, G3 and G4. The voltages for the cathode, G1 and G2 of each electron gun are applied separately.

Figure 5-16(b) shows an arrangement where the G1s, G2s, G3s and G4s of the three electron guns are connected to each other. This structure is compact. However, a common supply for the G1s and G2s is not favourable.

The electron gun arrangement shown in Figure 5-16(c) is a composite of the properties of structures (a) and (b). The arrangement shows three electron guns with separate G1s and G2s. The G3s and G4s, however, are connected.

Figure 5-16(d) is the common lens type, having one electron gun with three independent cathodes. The electron beams share the same G1, G2, G3, and G4 electrodes.

As shown in (a), (b) and (c), the bi-potential electrodes G3 and G4 work independently to focus three electron beams. In (d) the uni-potential electrodes G3, G4 and G5 work together to focus the beams.

The common lens type in (d) is a very compact structure, with the main convergence lens having a bigger diameter, thus possessing more merits than the other structures. However, voltages cannot be applied independently to the electrodes, only to the cathodes.

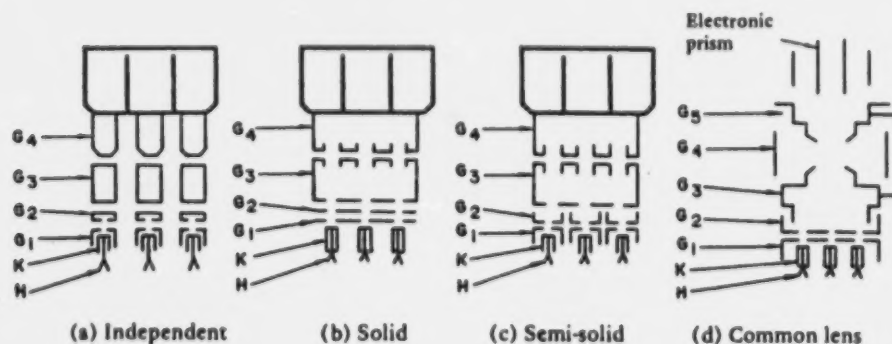


Figure 5-16
Structure of in-line three-beam electron gun

The characteristics of the colour picture tube

Electrode voltage. Except for the anode, the voltages for the rest of the electrodes are supplied to the base pins. The configuration of the base pins differs in every type of CRT, and it is advisable to refer to the CRT manuals for the correct configuration.

The anode is also connected to the aquadag coating (conductive graphite coating) inside the CRT, the shadow mask and the metal back (aluminium coating) of the phosphor screen. The anode voltage (E_b) is supplied through the anode button on the cone of the CRT. E_b is around 16 to 20 kV for small and medium colour CRTs and 23 to 25 kV for large colour CRTs.

For the bi-potential CRTs the voltage of the focus electrode G3 is about one fourth or one sixth of the anode voltage. This voltage should be adjusted to get the best focus.

For the uni-potential CRTs G4 is usually the focus electrode. The focus voltage applied to G4 can be adjusted within the range of 0 to 400 V.

The voltage of the second grid (also called the *screen grid*) is set between 200 and 600 V with respect to the cathode to adjust the white balance. The filament voltage is generally 6.3 V AC. The filament current ranges from 0.3 to 0.9.

Modulation and drive characteristics. For the electron gun structures shown in Figures 5-16(b) and (d), where all the electrodes are common except for the cathodes, the three video signals matrixed with red, blue and green are applied to the three independently controlled cathodes.

For the electron gun structures shown in Figures 5-16(a) and (c), where each of the three electron beams is controlled by G1 of each electron gun, the Y signal is applied to the cathodes and each of the colour-subtraction signals (R-Y, G-Y, B-Y) is applied to the G1 of the proper electron gun.

Brightness and contrast. The brightness of the colour CRT screen will be proportional to the amount of electrons the shadow mask has allowed to pass. (Only 15 to 20 per cent of the electron beam passes through the shadow mask.)

The brightness can be increased by increasing either the anode voltage or the beam current. However, excessive increase in the anode voltage causes more X-ray radiation and excessive increase in beam current causes blooming. The symptom of blooming was described in the section on "Focus." This symptom will cause some part of the picture, particularly the bright part, to be out of focus.

The maximum value for the beam current without blooming varies with different types of the CRT. The total magnitude of the three beam currents is about 1,200 μ A at the time of the white peak.

The brightness of the colour CRTs is important in the reproduction of the picture. However, picture quality depends on maintaining a constant contrast ratio even under bright external lights.

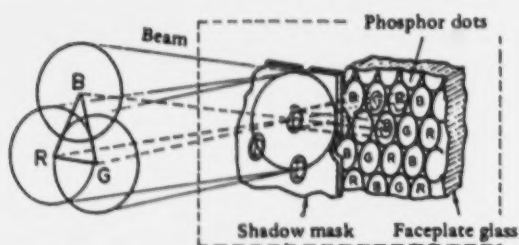
The contrast ratio in black-and-white CRTs is improved by using a dark-tinted faceplate for filtering, as previously discussed in the section on "Contrast Ratio and the Transparency of the Faceplate." However, it is not advisable to use a filter on colour CRTs with brightness lower than the black-and-white CRTs. This is because of the low percentage of the beam that passes through the sha-

dow mask. A filter will lessen the brightness so much.

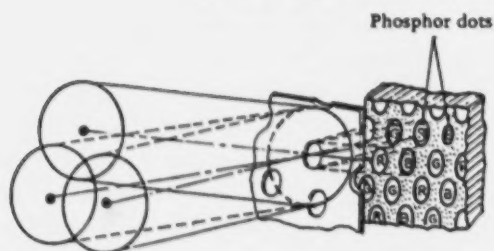
The contrast ratio is maintained efficiently by using a black matrix luminescent (BML) screen. Compared with the ordinary luminescent screen, the BML screen reduces the amount of reflected external lights to 50 per cent. Therefore, with the BML screen, a relatively clear glass with 85 per cent transparency is used for the faceplate.

Black matrix phosphor screen

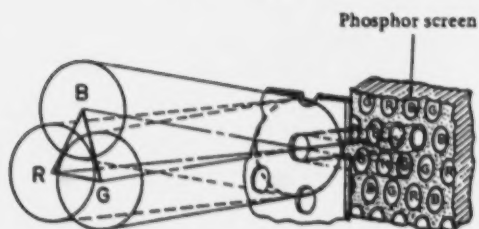
As shown in Figures 5-19(b) and (c), the black matrix phosphor screen is made by having gaps painted with a black substance (such as lead) between the phosphor dots on the screen. There are two types of black matrix luminescent (BML) screens: the negative BML screen [see Figure 5-19(b)] and the positive BML screen [see Figure 5-19(c)].



(a) Ordinary phosphor screen



(b) Matrix phosphor screen,
Negative type



(c) Black matrix phosphor screen,
positive type

Figure 5-19
Black matrix phosphor screen

The screen of conventional colour CRTs shown in Figure 5-19(a) contains phosphor dots with diameter slightly larger than the diameter of the holes of the shadow mask. Note that the diameter of the electron beams hitting the phosphor screen after converging at the shadow mask hole is equal to the diameter of the holes of the shadow mask, hence smaller than the phosphor dots. Therefore, when only a slight error in beam landing occurs, the beams do not hit the adjacent dots. This reduces colour fringing.

The phosphor dots of the negative BML screen [see Figure 5-19(b)] are smaller than those of the conventional phosphor screen, the holes of the shadow mask of the negative BML screen are bigger. The diameter of the electron beam in the BML is larger than the diameter of the dots.

Since there are gaps between the dots when only a slight error in beam landing occurs, the beams do not hit the adjacent dots. With this kind of screen, the tolerance in the error of beam landing and the effective lighting area is similar to that of the conventional phosphor screen. However, since the gaps between the dots are painted black, the reflection of external lights compared with the conventional phosphor screen is reduced to 50 per cent. Therefore, using the BML screen improves the contrast ratio by as much as 100 per cent without sacrificing colour purity and brightness.

One of the major problems in using the BML screen is the difficulty in getting a pure white raster. In conventional phosphor screens the area of the phosphor dots that emits light is determined by the diameter of the electron beam, not the size of the phosphor dots. Since the diameter of the electron beam is equal to the diameter of the shadow mask holes, the effective area of the dots emitting light and consequently the amount of light emitted by each dot are similar all over the screen. Therefore the sizes of the phosphor dots on the screen do not have to be exactly the same.

In the BML screen, however, the diameter of the electron beams is larger than that of the phosphor dots. Therefore the diameter of the dots determines the area that will emit light and consequently the amount of light.

If the sizes of the dots are not exactly the same all over the screen, the intensity of light emitted by each colour phosphor is not uniform throughout the screen. This causes the difficulty in getting a pure white raster.

Thus high-precision technology is needed to print the phosphor dots on the screen as well as a special process to print dots on the screen with diameters less than the diameter of the holes of the shadow mask. The diameter of the shadow-mask holes of the positive BML screen is equal to the diameter of the holes of the conventional screen. A positive BML screen can therefore be made by small changes in the production line of conventional colour CRTs.

Quick-start cathode

Solid-state technology is used in the circuitry of modern TV receivers. Solid-state components require no warm-up; they function as soon as power is applied. In TV receivers, however, the CRT is still a conventional vacuum tube that requires warm-up before it operates. It usually takes around 20 seconds before a raster is produced.

Since 1973 the pre-heating method of the filament has been used to reduce the warm-up time when the power switch is on. Sixty-five per cent of the heater voltage is supplied to the CRT while the power switch is off. This method, however, consumes five to ten watts of electric power. The quick-start cathode was developed to conserve energy. CRTs with a quick-start cathode will produce a raster on the screen four to five seconds after the power switch is turned on without pre-heating.

The structure of the quick-start cathode varies with different makers. However, the following characteristics are common: 1) the cathode is smaller, thus heat requirement is less and the heating time is short; 2) the filament coil is double-wound to yield a higher heat-generating efficiency; and 3) the efficiency of heat transfer between the heater and the cathode is improved

Surrounding parts of the colour CRT

Various components are mounted on the neck of the colour CRT to adjust the direction of the electron beam before it is turned aside by the deflection yoke. The adjustment method can be divided into two: 1) using a permanent magnet (static deflection) and 2) using coils (dynamic deflection).

These surrounding components differ in structure and kind of every CRT, but examples of the delta gun and in-line gun CRTs are shown in Figure 5-20 and Figure 5-21, respectively. In some in-line colour CRTs the dynamic convergence coil is omitted and convergence is done statically.

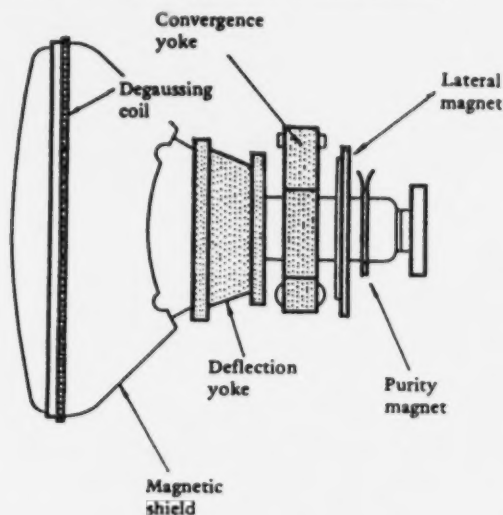


Figure 5-20
Surrounding components
of a delta gun colour CRT

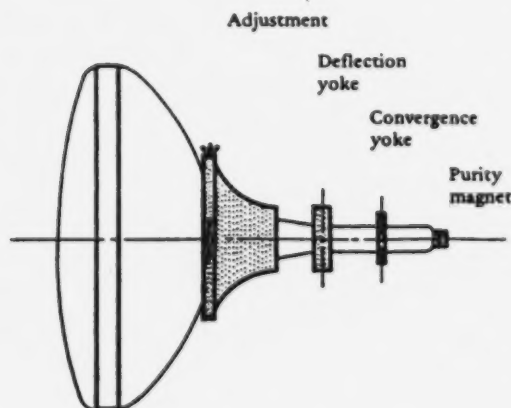


Figure 5-21
Surrounding components of the
three-gun, three-lens in-line colour CRT

To counteract the effects of external magnetic fields, a steel cover is placed around the cone of the CRT and a degaussing coil around the shadow mask. The steel cover shields external magnetic fields and the degaussing coil demagnetises the shadow mask. For black-and-white CRTs the deflection yoke and the centring magnets are the only components mounted on the neck of the CRT.



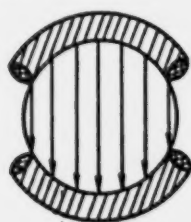
Picture 3-1
A deflection coil

Deflection yoke. As shown in Picture 3-1, the deflection yoke has specially shaped coils. These coils consist of the horizontal and vertical deflection coils. The inner coil is the horizontal deflection coil, the outer coil the vertical deflection coil. The deflection coil used for the delta gun colour CRT is shown in Figure 5-22(a).

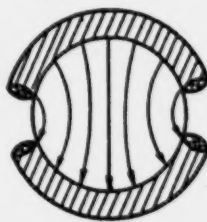
The magnetic field produced by this coil is constant and the lines of flux are straight. This kind of magnetic field produces a distorted raster. The raster is pulled at the edges and compressed in the middle. This is pincushion distortion; therefore the pincushion circuit is used to get the proper rectangular raster.

For the in-line CRTs the magnetic field produced by the horizontal deflection is spool-shaped; the magnetic field produced by the vertical deflection coil is barred-shaped, as shown in Figures 5-22(b) and 5-22(c), respectively. With these kinds of magnetic fields, the raster will be rectangular and the precision of the convergence improved.

(a) Constant magnetic field



(b) Bobbin-shaped magnetic field



(c) Barrel-shaped magnetic field

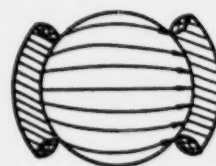


Figure 5-22
Magnetic field within a deflection coil

Purity magnet. In colour CRTs the arrangement of the three electron guns is designed so that the three electron beams will converge at the centre of the shadow-mask hole. However, in actual instances the three electron beams do not always converge at the centre of the hole, because of the slight misalignment of the electron guns. Thus a purity magnet is needed to adjust the path of the electron beams so that they will converge at the centre of the hole. The structure of the purity magnet is shown in Figure 5-23.

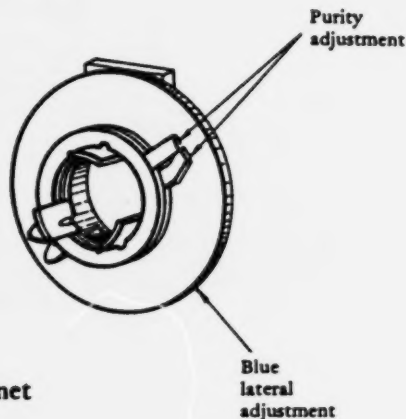


Figure 5-23
A purity magnet

Convergence yoke. In colour CRTs the three electron beams must converge at the holes of the shadow mask and then hit their corresponding phosphor dots on the screen. If this happens, colour reproduction is properly done. However, if the three beams do not converge at the holes and do not hit their corresponding phosphor dots, colour fringing occurs.

There are two kinds of colour fringing: colour fringing all over the screen and partial colour fringing. Colour fringing all over the screen happens when the three electron beams do not converge at the holes of the shadow mask and do not hit their respective phosphors. To eliminate this, the direction of each beam has to be precisely adjusted individually until the three beams converge at the holes of the shadow mask and hit their corresponding phosphors. This is like having three different bullets pass through one hole instantly but hit different targets.

Figure 5-11 shows three different gun arrangements, with the three beams converging at a hole of the shadow mask and hitting only their corresponding phosphors. This adjustment of the directions of the electron beams is called *static convergence adjustment*.

A set of permanent magnets is used for static convergence to eliminate colour fringing all over the screen. Convergence coils are used for the dynamic convergence adjustment to eliminate partial colour fringing. The coils consist of the vertical and horizontal convergence coils. A current with a special wave-form synchronising the current through the deflection coils is supplied to the convergence coils.

Lateral magnet. This magnet is used only for the lateral movement of the blue beam in delta gun CRTs. Because of the arrangement of the guns in delta gun CRTs, it is necessary to move the blue electron beam laterally for it to converge with the red and green beams. For this purpose, a lateral magnet shown in Figure 5-24 is attached between the purity magnet and the convergence yoke. This magnet is considered a part of static convergence adjustment. In some CRTs the positions of the purity magnet and the lateral magnet are interchanged.

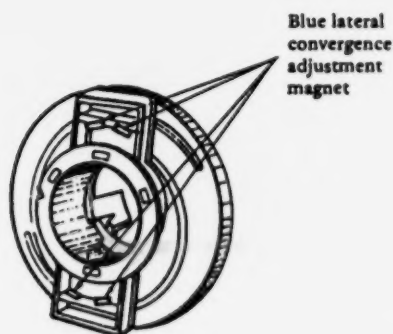


Figure 5-24
A lateral magnet

Degaussing coil. The magnetic field of the earth is strong enough to magnetise the shadow mask. A magnetised shadow mask affects the direction of the electron beam. When the beam direction is affected, colour fringing occurs; therefore the shadow mask must be demagnetised.

A degaussing coil mounted around the faceplate (see Figure 5-20) is used to demagnetise the shadow mask. The shadow mask is demagnetised by the decaying magnetic field produced by the decaying AC current supplied to the coil.

Convergence

As mentioned earlier, convergence is very important in colour CRTs. Besides the conventional types of CRTs, three major kinds of in-line CRTs have been developed. These CRTs are commonly used in modern TV receivers. The procedure for adjusting the convergence varies in different types of CRTs.

Delta gun CRT

Static convergence adjustment. By adjusting the permanent magnets of the static convergence adjustment shown in Figure 5-25(a), one changes the strength and direction of the magnetic field within the magnetic shield for each beam. The magnetic field will move the electron beams radially. The displacement of the electron beams is proportional to the strength of the magnetic field.

Figure 5-25(b) shows that the green and red beams will converge at a point. However, since the blue beam is displaced only radially, it has to be moved laterally to converge with the green and red beams. The blue beam is moved sideways by a lateral magnet. This adjustment of the blue beam is called the *lateral adjustment*.

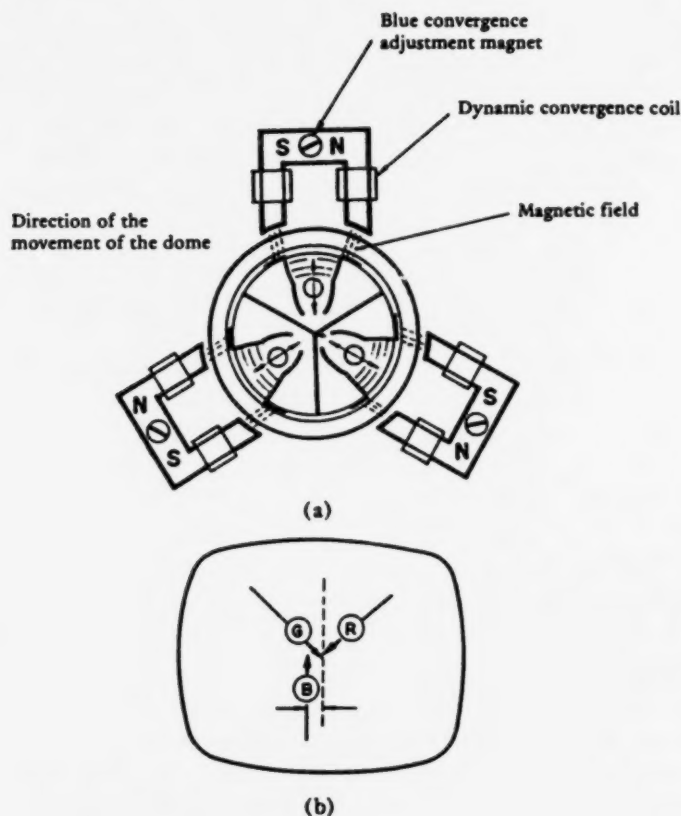


Figure 5-25
Components of static convergence
adjustment and static convergence adjustment

Dynamic convergence adjustment. As described before, adjusting the beams' convergence on the centre of the screen is done by the static convergence adjustment. The dynamic convergence adjustment converges the beams at every hole of the shadow mask all over the screen.

Figure 5-26 shows the parts of the screen where the beams do not usually converge.

The horizontal and vertical convergence circuits are designed to supply the horizontal and vertical dynamic convergence coils respectively with a parabolic sawtooth current. This current is taken from the deflection circuits and, after being processed by the convergence circuits, is supplied to the convergence coils. The current through the convergence coils will converge the beams all over the screen.

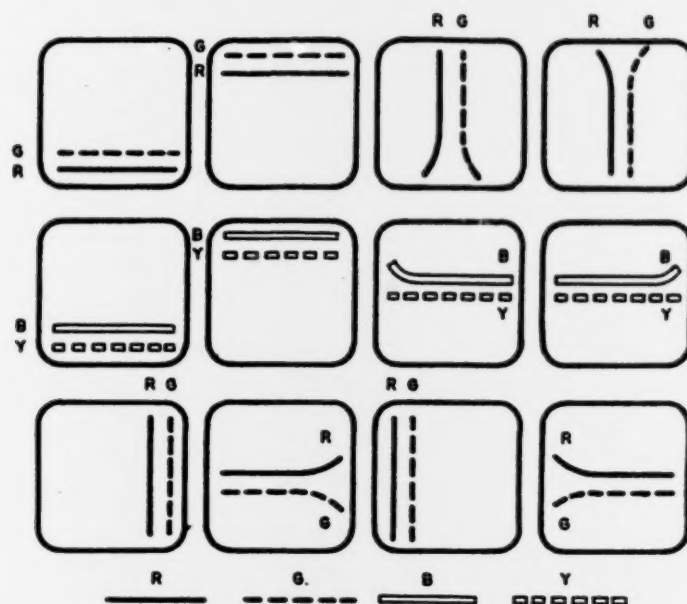


Figure 5-26
Typical poorly converged picture
(Y indicates yellow)

1) Vertical convergence circuit.

Figure 5-27 shows a vertical convergence circuit for the blue beam. The sawtooth voltage is tapped from the emitter of the vertical output transistor. This wave is integrated by VR1 and the blue convergence coil L. Therefore a parabolic current will flow in L.

On the other hand, a pulse voltage appears at the secondary winding of the vertical output transformer T during the retrace period. This voltage is integrated by VR2 and L. Therefore a sawtooth current will flow in L. Thus the resulting current that will flow through L is a mixture of a sawtooth and a parabolic current. The wave-form of the resulting current is shown in Figure 5-28.

The convergence adjustment is done by varying the amplitude and the shape of the current through L by VR1 and VR2, respectively. The circuit and

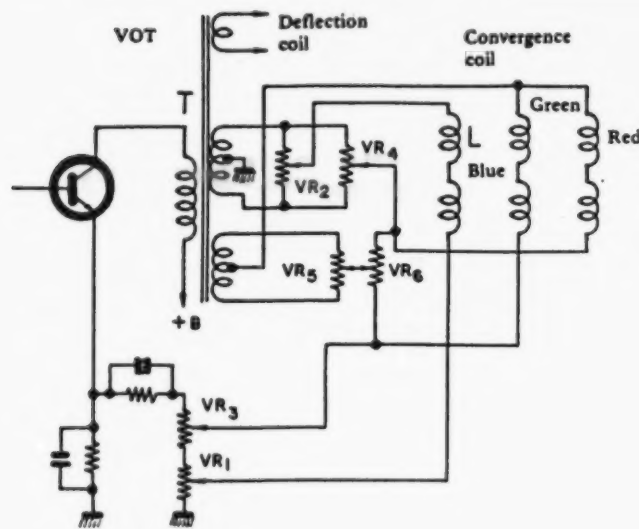


Figure 5-27
A vertical convergence circuit

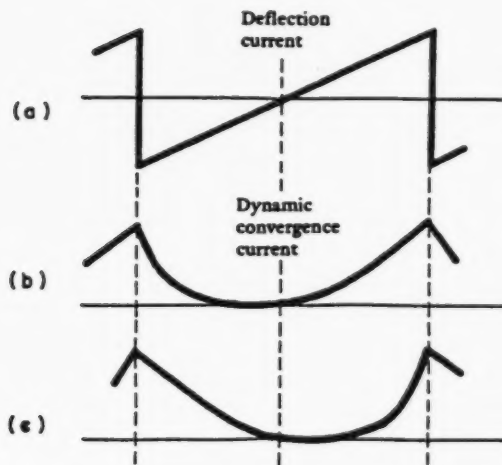


Figure 5-28
A parabolic current

principle of the vertical dynamic convergence adjustment of the red and green beams are similar.

2) Lateral convergence circuit.

Figure 5-29(a) shows a lateral convergence circuit, Figure 5-29(b) a blue lateral convergence circuit. The pulses from the horizontal deflection circuit are used as a power source.

The values of $L1$, $C1$ and $C2$ are so designed that the circuit resonates at around 15.75 kHz (horizontal oscillator frequency).

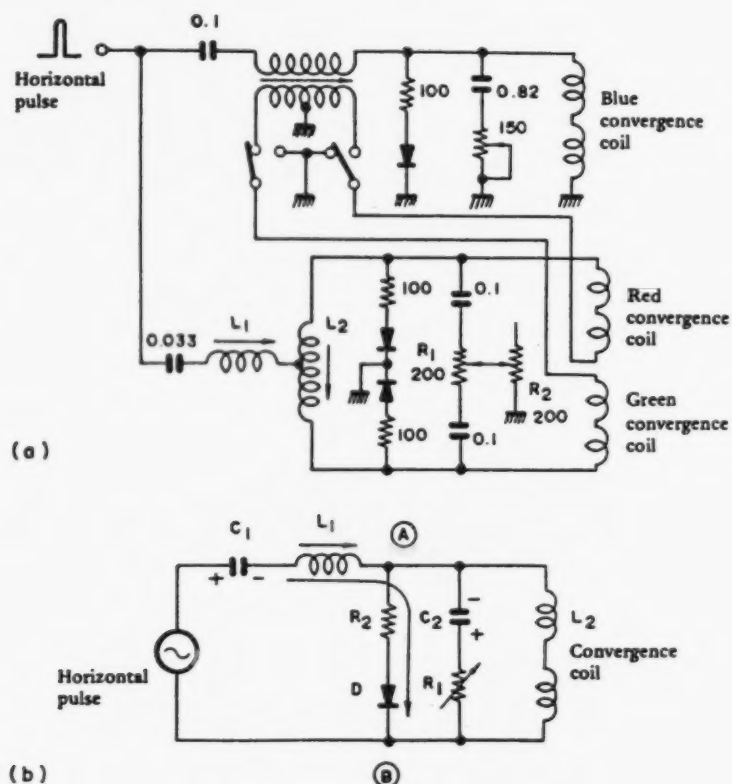


Figure 5-29
A horizontal convergence circuit

When R_1 is set to minimum (0 ohm), a sinusoid-like wave-form with a 90-degree phase shift with respect to the input will appear between points (A) and (B). The current shown in Figure 5-30(a) will flow in coil L_2 .

When the value of R_1 increases, the quality factor Q between (A) and (B) decreases. With a high value of R_1 , C_2 is negligible. Thus the resulting current that will flow through L_2 will have a phase lead over the current that will flow through the coil when R_1 is minimum. See Figure 5-30(b).

Lateral convergence adjustment is done by changing the phase and the amplitude of the current in L_2 . Variation in current and resistance in L_1 and R_1 changes current flow in L_2 .

In practical applications, the dynamic convergence adjustment for converging the beams at the centre of the screen is not needed. Therefore, R_2 and D are connected in parallel to L .

When point (A) becomes positive with respect to point (B), diode D conducts, clipping the upper part of the sinusoid-like wave. Hence the current that will flow through L_2 will be a parabolic current. Thus this lateral convergence adjustment circuit converges the beams at the right and left edges of the screen.

As shown by the wave-forms in Figure 5-30, varying the value of L_1 while keeping R_1 constant changes the shape of the wave-form more at the later part

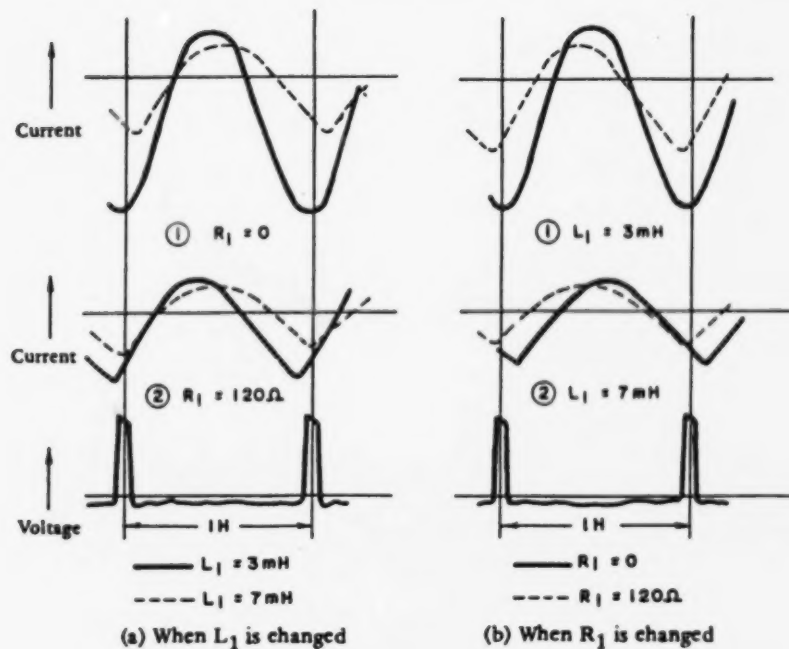


Figure 5-30
Current change in convergence coil
when the values of L_1 and R_1 are changed

of the horizontal scanning period. Varying the value of R_1 while keeping L_1 constant changes the shape of the wave-form more in the earlier part of the horizontal scanning period. Thus L_1 is adjusted to converge the beams at the right edge of the screen; R_1 to converge them at the left.

In-line picture tube

The static and lateral dynamic convergence adjustments are needed for this kind of colour CRT.

Static convergence adjustment. In the in-line colour picture tube the three electron guns are placed side by side forming a plane. The centre electron gun (green or red) is mechanically aligned with the centre axis of the picture tube during manufacturing.

For this kind of arrangement, convergence is needed only for the outer beams. Thus the structure of the convergence coils becomes simple. However, the vertical dynamic convergence adjustment and the static convergence adjustment can be omitted if a self-convergence deflection yoke is used.

In the three-lens in-line gun, an E-shaped convergence yoke is used. (See Figure 5-31.)

Two permanent magnets mounted on each yoke can be rotated to displace the outer beams diagonally to converge the outer beams with the centre beam at the shadow mask.

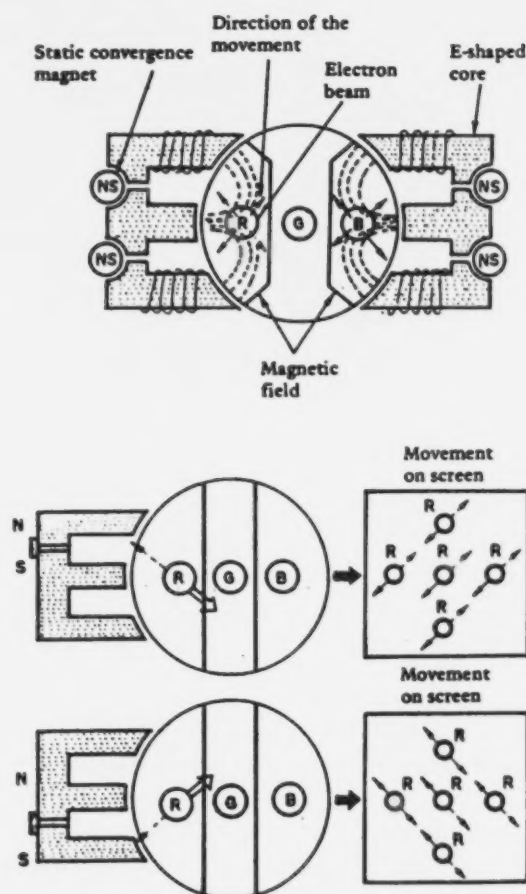


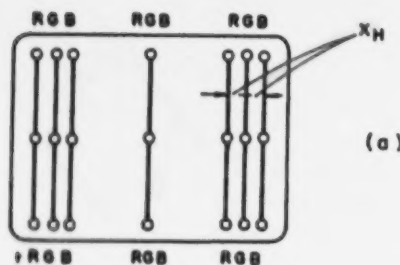
Figure 5-31
Convergence yoke and static convergence
of a three-gun, three-beam colour CRT

Dynamic convergence. Using the self-converging deflection yoke in the three-gun, three-lens colour CRTs, only the horizontal dynamic convergence of the beams is affected.

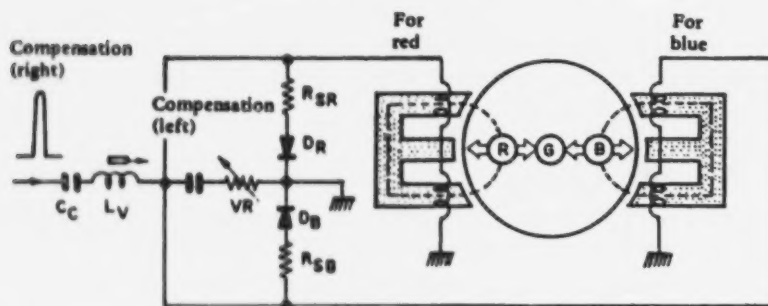
The vertical lines at the edges of the screen represent the symmetrical deviation of the green and red beams from the blue beam when the beams are deflected horizontally. The deviations of the outer beams increase as the beams are further deflected horizontally.

The parallel vertical lines indicate that the direction of the beams with respect to each other is not affected when they are deflected vertically. Thus, only the horizontal or lateral dynamic convergence adjustment is needed.

Figure 5-32 shows the circuit of a lateral convergence adjustment. The circuit for the red beam is symmetrical to the circuit for the blue beam. In this circuit a parabolic current with horizontal oscillator frequency flows through the convergence coils. The magnetic fields produced by the current are controlled by VR and LV to move the outer beams laterally.



(a) Colour fringe on the side of the screen



(b) Dynamic convergence circuit

Figure 5-32
Functional circuit of dynamic
convergence circuit

VR is adjusted to converge the beams at the left part of the screen; L_V to converge them at the right part. The convergence circuit for the one-gun, three-lens colour CRT is more complicated than that for the three-gun, three-lens colour CRT.

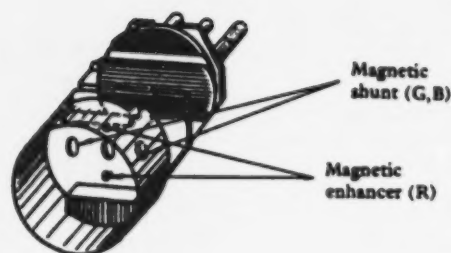
Self-converging picture tube. To make the self-convergence of the in-line colour CRT possible, one pays technical attention to the structure and magnetic field of the deflection yoke. The deflection yoke and the CRT are made as one piece.

- a The guns are designed as close as possible.
- b The order of the setting of the phosphor screen is vertical-striped.
- c For dynamic convergence adjustment, a magnetic enhancer and shunt shown in Figure 5-33 are placed at the tip of the electron gun to emphasise and control the electron beam, respectively. The enhancer and shunt compensate for the different sizes of the raster made by the centre and outer beams.

a A specially designed deflection yoke is used to produce a barrel-shaped magnetic field for the vertical deflection and a spool-shaped magnetic field for the horizontal deflection.

Principle of self-convergence. The vertical self-converging deflection yoke is designed to produce a barrel-shaped magnetic field, as shown in Figure 5-34(a). The vertical component of the magnetic field where the B and G beams are located is opposite. Therefore using Fleming's left-hand rule, the forces exerted by these components are opposite. The B beam will be moved to the left, the

Figure 5-33
Component of magnetic field adjustment used in self-converging colour CRT



G beam to the right.

Structurally, the distance between the deflection centres of the beams and the phosphor screen becomes greater at the corners and edges of the picture screen than at the centre. Therefore, if an ordinary deflection yoke which produces a constant magnetic field is used, the deviation in beam landing will be greater at the edges.

On the upper-left edge of the screen, as shown in Figure (b), the G beam is deflected more than the R beam by the vertical component of the magnetic field, so that the G beam is driven further to the left than the R beam.

On the other hand, in the B beam the distance between the deflection centre and phosphor screen is smaller than the R beam. The B beam is not deflected sufficiently, thus landing on the right of the R beam on the screen.

To compensate for these deviations, one uses the self-converging deflection yoke, producing a barrel-shaped magnetic field. The vertical component of this magnetic field will shift the G and B beams in opposite directions to make them land on the same point as the R beam.

On the other hand, the horizontal component of the barrel-shaped magnetic field is greater at the position where the B and G beams pass than at the position where the R beam passes. Therefore the vertical deflection of the R is smaller than the B and G beams.

Figure 5-34(a) shows three electron beams being deflected to the upper side of the screen. The same principles apply if the beams are deflected to the lower side.

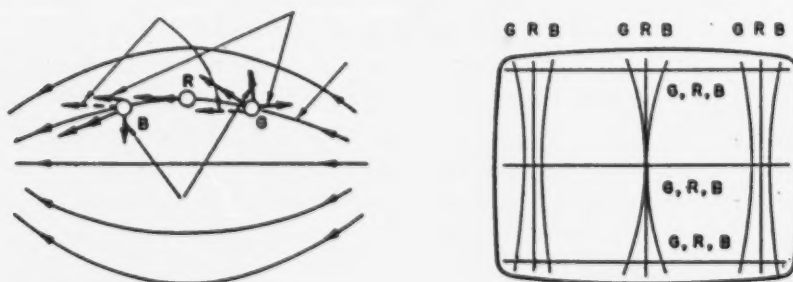


Figure 5-34
A barrel-shaped magnetic field

As shown in Figure 5-35(a), the rasters produced by the B and G beams are exactly the same and the raster produced by the R beam is a little smaller.

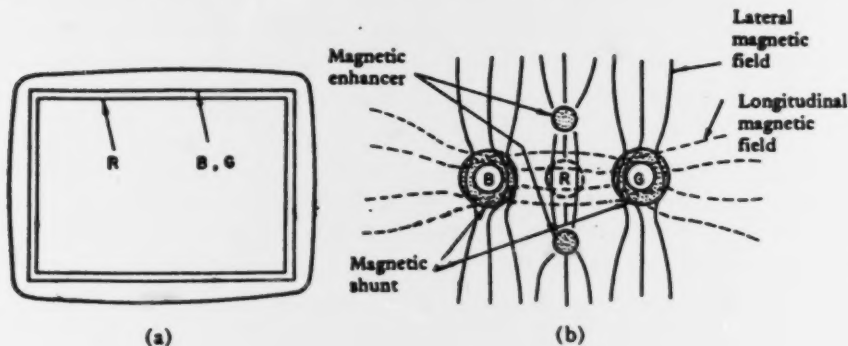


Figure 5-35
Magnetic enhancer for red beam and
magnetic shunt for green and blue beams

To compensate for the difference in raster size, a magnetic shunt is placed at the tip of the electron gun to reduce the strength of the barrel-shaped magnetic field on the B and G beams. The effect of the magnetic shunt is the same even in horizontal deflection.

If the horizontal deflection yoke is made to produce a spool-shaped magnetic field, as shown in Figure 5-36(a), the vertical component of the magnetic field will be greater at the sides than at the centre.

When the beams are deflected to the right, a stronger magnetic field will be acting on the G beam than on the B to compensate for the difference in the distance travelled by these beams. Hence the B and G beams will land on the same spot on the screen, as shown in Figure 5-36(b).

In the R beam the magnetic enhancer is used to enhance the centre magnetic field, causing a bigger deflection of the R beam. This will make the R beam land on the B and G beams exactly.

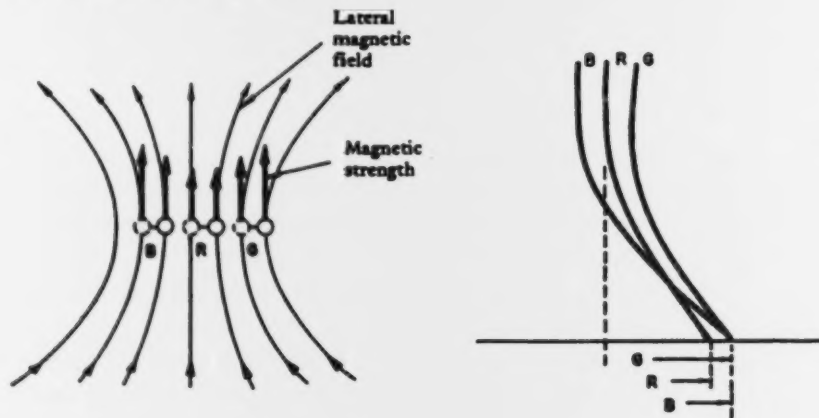


Figure 5-36
Spool-shaped magnetic field

In an actual self-converging colour CRT the structure of the electron guns and compensating magnets is designed to get the same result.

The magnetic enhancer for the R beam and the magnetic shunt for the B and G beams are located at the tip of the electron gun, as shown in Figure 5-33. The magnetic enhancer consists of two small metal pieces sandwiching the R beam; the magnetic shunt is a small cylindrical electrode where the B and G beams pass through.

As shown in Figure 5-35(b), the shunt serves as a shield for the B and G beams against the magnetic field, so that the B and G beams will not be affected by the magnetic field when they travel through the shunt. However, the unshielded portion of the B and G beams will still be affected by the magnetic field. Nevertheless the net effect of the magnetic field on the B and G beams is reduced.

The magnetic enhancer is a small metal piece placed in the magnetic field to converge the horizontal magnetic field. Thus it produces a magnetic field which influences the R beam that passes nearby, enhancing the effect of the deflecting magnetic field on the R beam.

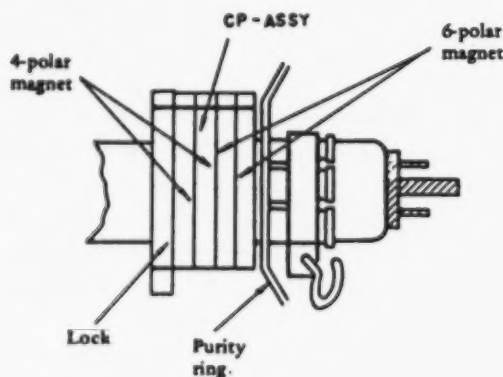


Figure 5-37
Components attached to the neck of a self-converging colour CRT

Accessories of the self-converging CRT. The self-converging colour CRT requires the dynamic convergence adjustment but not the static convergence and the purity adjustments. The assembly of magnets shown in Figure 5-37 is used for the self-converging CRT and constructed as one piece.

The purity magnet moves the electron beams laterally so that they will meet with the axis of the tube.

For the static convergence adjustment, two pairs of magnetic plates are used. These consist of four- and six-polar magnets. The four-polar magnet displaces the B and G beams equally in opposite directions, as shown in Figures 5-38(a) and (b). The amount of displacement is varied by the angle of the plates, and the direction of the beams is controlled by the rotation of magnets.

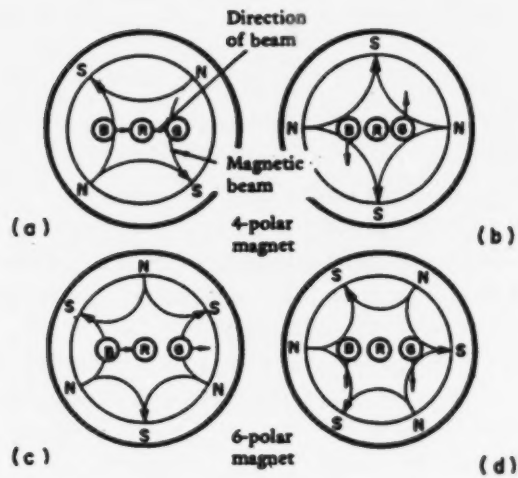


Figure 5-38
Four- and six-polar magnetic plates

The six-polar magnet changes the direction and position of the B and G beams equally. Again, the rotation angle controls the amount of displacement and direction by the rotation of magnets.

Picture tube circuit

Brightness-control circuit

If the anode voltage is constant, the brightness of the picture tube depends on the amount of the electron beams hitting the screen. Therefore, by varying the bias voltage, the brightness of the screen can be changed.

Figure 5-39 shows the relationship between the brightness of the screen and the instant grid voltage for different values of DC bias voltage.

In (a) the DC bias voltage is so little that the screen still emits light even though the video signal has reached its black level.

In (c) excessive DC bias voltage causes the screen to reproduce the grey and white level of the video signal as black and grey, respectively. In both cases, the correct brightness of the original picture is not properly reproduced.

Figure 5-42(b) shows the proper DC bias. With a proper DC bias, the black level of the video signal coincides with the cut-off voltage of the CRT. Present black-and-white TV receivers have no DC restoring circuit for the DC bias, and only the AC component of the video signal is coupled to the CRT. Thus a brightness-control circuit is used to adjust the average brightness of the screen.

Figure 5-40 shows a brightness-control circuit in black-and-white TV receivers.

In colour TV receivers the brightness is controlled by adjusting the emitter voltage of the second, third or fourth video amplifier transistors.

Figure 5-41 shows a brightness-control circuit in a colour TV. The emitter voltage of the fourth video amplifier is varied by adjusting the brightness-control potentiometer VR1. A decrease in the emitter voltage increases the collector

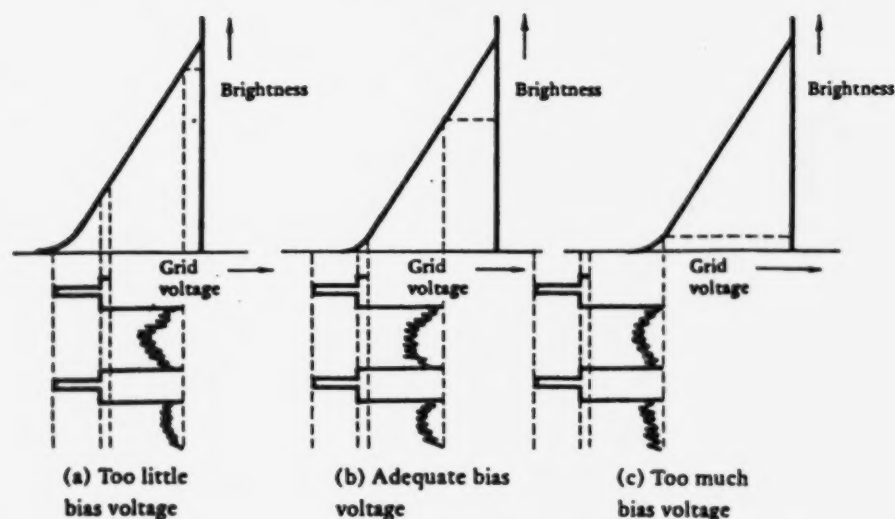


Figure 5-39
Grid voltage and brightness

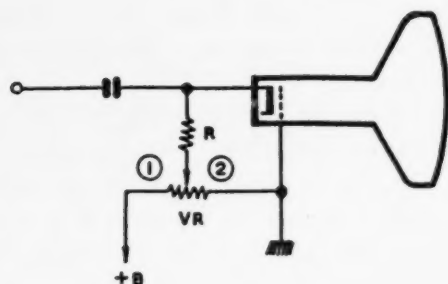


Figure 5-40
Principle of a brightness-control circuit

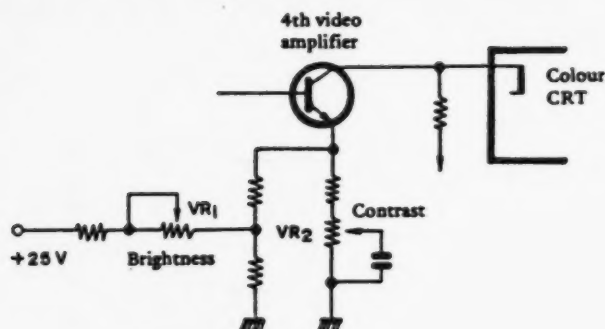


Figure 5-41
Brightness-control circuit of a colour CRT

current and reduces the collector voltage. Since the collector is directly coupled to the cathode of the CRT, the brightness of the screen will increase if VR1 is adjusted so that the emitter voltage decreases.

White balance adjustment

A colour TV receiver should be able to reproduce a good quality monochrome picture when a black-and-white video signal is received. The electrode voltages and the drive voltage should be adjusted so that a good monochrome picture is reproduced. This is called the *white balance adjustment*. Poor white balance will cause the monochrome picture, particularly the bright parts, to have colours.

The light-emission efficiency of the three coloured phosphors should be the same for a proper white balance. However, because of the slight differences in the light-emission efficiency of the phosphors, the beam current ratio of the R, G and B beams is set to 34:34:32 to get a white balanced raster.

A white balance adjustment circuit is shown in Figure 5-42(a). This circuit is used in colour TVs using the colour-subtraction drive system. The voltages of the three screen grids of the CRT are set to the cut-off voltage by adjusting a variable resistor for each grid. The drive-control circuit compensates for the differences in the characteristics of the three electron guns to produce the proper beam current ratio.

Figure 5-42(a) shows G-drive and B-drive control circuits. This kind of white balance adjustment circuit is commonly used in delta-gun and three-gun, three-lens in-line colour CRTs.

The white balance adjustment circuit for the primary-colour drive output varies slightly among different CRTs. In in-line colour CRTs where the G1s and G2s are connected, voltages for each grid cannot be adjusted individually. The circuit shown in Figure 5-42(b) is used for the white balance adjustment of this kind of CRT. This circuit is also used in in-line CRTs where the three electron beams share the same lens.

In this circuit the voltage for the screen grids is set to the cut-off voltage by adjusting a single variable resistor (BKG-VR). The ratio of the beam currents is adjusted by changing the amplitude of the Y signal applied to the emitter of the primary-colour output transistor. This amplitude is varied by adjusting the R- and B-drive controls.

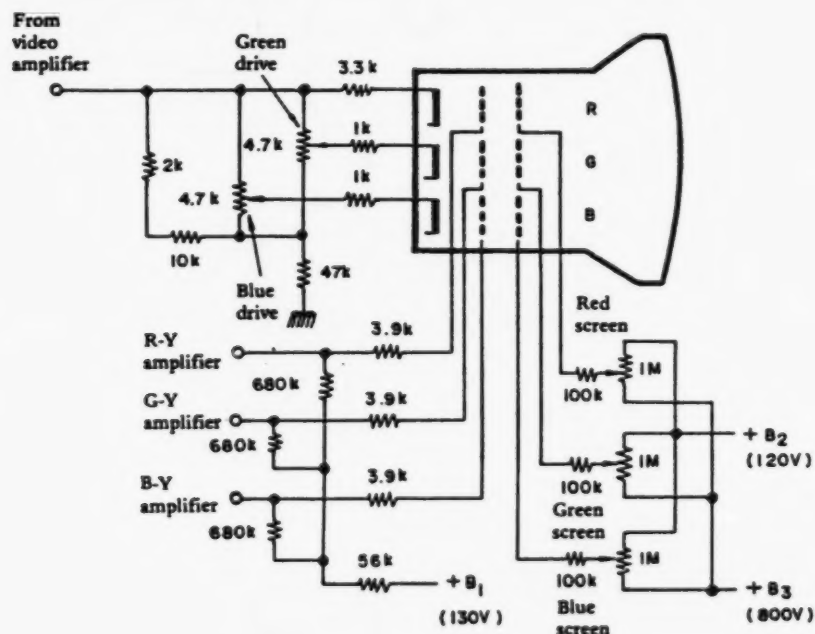


Figure 5-42(a)
White balance adjustment circuits and
colour-subtraction drive circuit

Focus circuit

To get sharp pictures on the screen, one applies a focus voltage to the focus grid. The electric field between the focus grid and the accelerator grid (anode) serves as a static lens that focuses each of the electron beams.

As discussed in the section on "General Characteristics of a CRT," focusing the electron beam by applying a focus voltage to the focus electrode is called *static focusing*. As mentioned before, there are two types of static focusing: uni-potential and bi-potential.

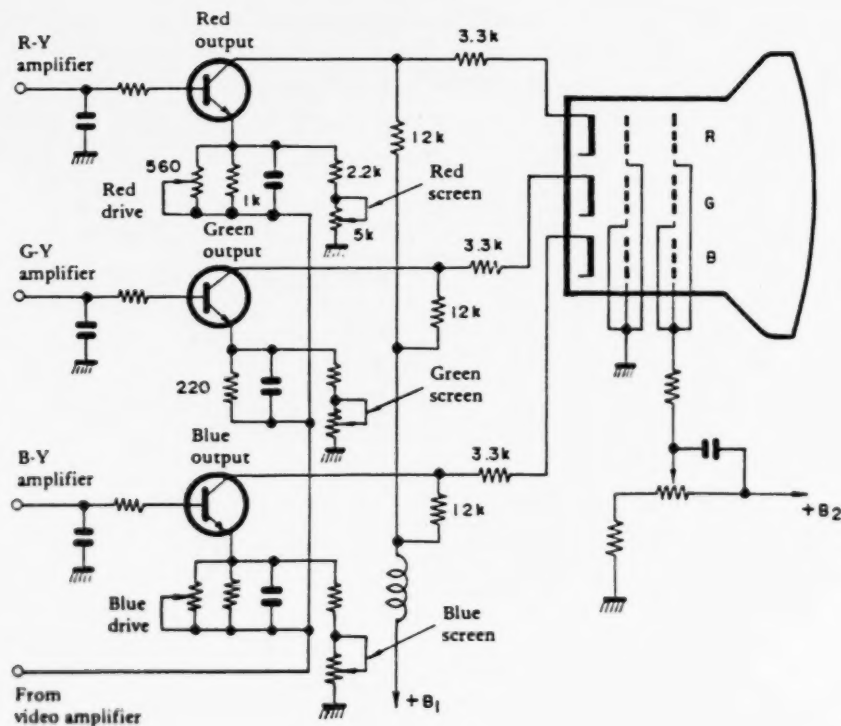


Figure 5-42(b)
White balance adjustment circuits and
primary-colour drive circuit

Uni-potential focusing. This type is commonly used in black-and-white CRTs and small colour CRTs. Figure 5-44(a) shows a circuit used for this kind of focusing. The focus voltage is taken from G2 and ranges from 0 to 400 V.

Bi-potential type. The circuit for this type of focusing is shown in Figure 5-44(b). The voltage applied to the focus grid is taken from the high-voltage rectifier circuit. This voltage is usually around 20 per cent of the anode voltage.

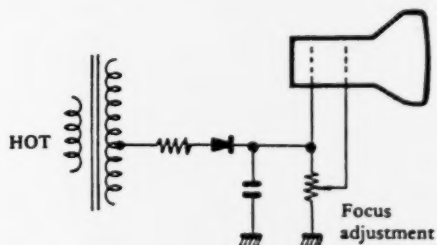
Automatic digesting coil

As described in the section on "Basic Structure and Principles of the Colour Picture Tube," poor purity results when the shadow mask is magnetised. To demagnetise the shadow mask, one mounts a digesting coil around it. Automatic degaussing is done when the TV set is switched on.

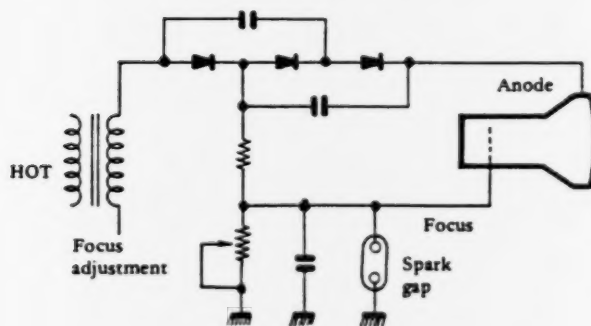
An AC current that gradually decreases in magnitude will produce a magnetic field around the shadow mask to demagnetise it. (See Figure 5-45 for the wave-form of the applied current.)

Several types of digesting circuits are used. Figure 5-46 shows one which uses a combination of a thermistor and a VDR (voltage-dependent resistor). When the power switch is turned on, the resistance of the thermistor is at first high because it is cold. On the other hand, the resistance of the VDR is low, so the current flows through the digesting coil first.

The temperature of the thermistor increases after some time, decreasing the resistance. Therefore current flowing in the thermistor increases. With a decrease in the resistance of the thermistor, the voltage across the VDR decreases by increasing its resistance.



(a) Uni-potential CRT



(b) Bi-potential CRT

Figure 5-44
Focus circuits

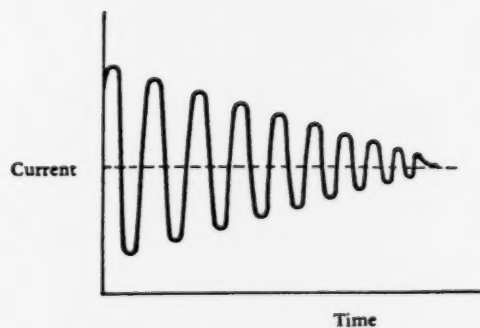


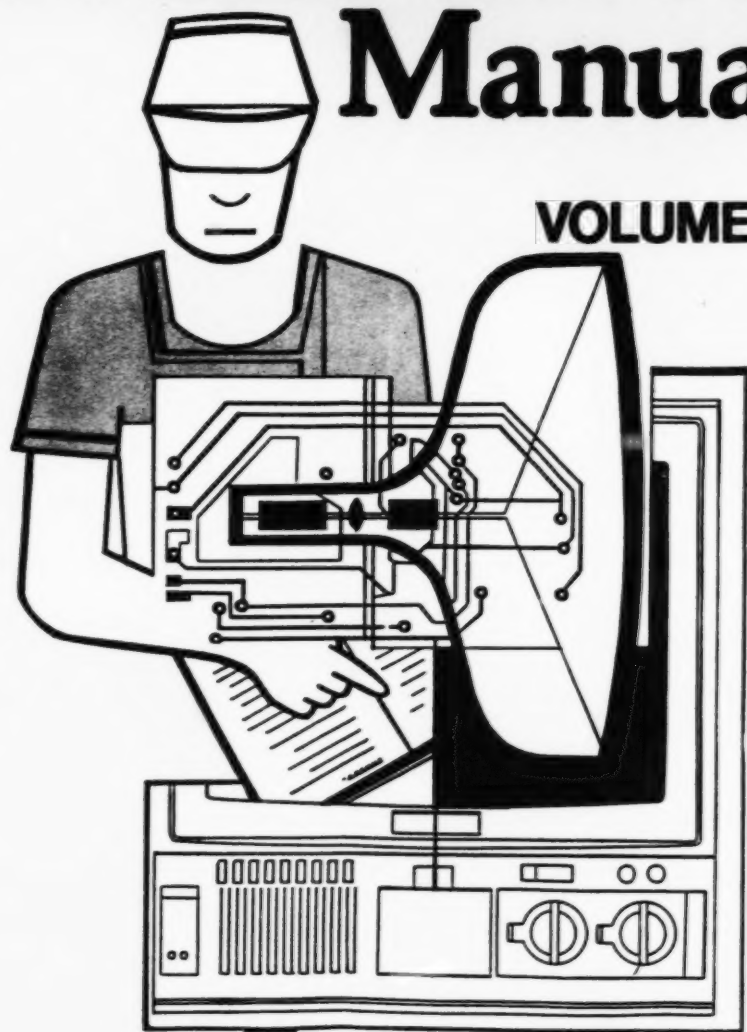
Figure 5-45
Ideal current flow in a degaussing coil



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TV Trouble-shooting Manual



BY MASAOKI MUKAI AND RYOZO KOBAYASHI

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Part 5: Picture tube and its surrounding circuit



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INTERNATIONAL LABOUR OFFICE
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Part 5: Picture tube and its surrounding circuit

Principle of the picture tube (CRT)

The picture tube, or the cathode-ray tube (CRT), is the last stage in transforming video signals into pictures on the screen of TV receivers. The CRT consists of an electron gun and a phosphor screen in an air-evacuated, bell-shaped glass envelope. The electron gun produces the electron beam. When the beam strikes the screen, the area bombarded by the electrons emits light. The electron beam is modulated and controlled by the video signal with the picture information needed to reproduce the original picture transmitted by the TV stations. The details in TV picture reproduction will be discussed using the black-and-white CRT as an example.

Basic structure and function of a black-and-white CRT

The basic structure of a CRT is shown in Figure 5-1. The electron gun and the phosphor screen are in a high-vacuum bell-shaped glass envelope. The glass envelope consists of a narrow neck and a cone. The phosphor screen is the bottom of the cone, coated with phosphor material. When the phosphor screen is hit by the electron beam, it emits light.

The electron gun is in the neck of the CRT. It consists of the cathode and several cylindrical electrodes. The cathode radiates electrons, the cylindrical electrodes perform other individual functions. The first electrode, called the control grid, concentrates and controls the amount of the electron beam that

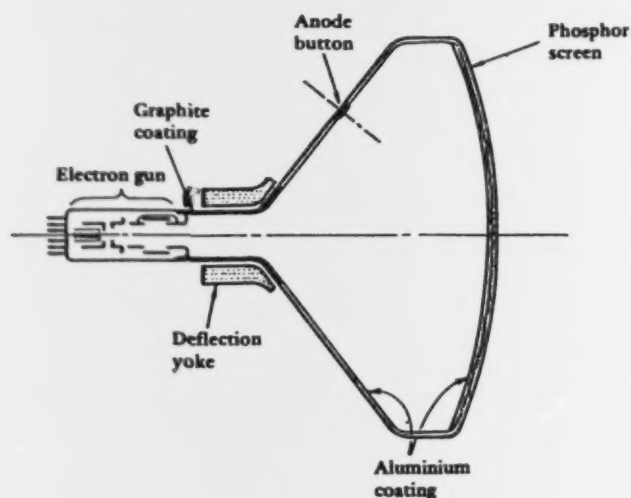


Figure 5-1
Basic structure of a CRT

reaches the screen. The other electrodes are the accelerator grid and the focus grid. The accelerator grid speeds up the electrons towards the screen. The focus grid focuses and converges the electron beam to a small spot on the screen.

The last electrode (generally the fifth) is called the high-voltage anode. It is connected to a conductive graphite coating sprayed inside the wall of the CRT. This coating is also connected to the aluminium coating (metal back) of the phosphor screen.

The initial speed (V) of the electrons emitted by the cathode is slow. These slow-moving electrons are speeded up by the accelerator grid. The final speed of the electrons depends on the accelerator voltage (E_b) applied to the high-voltage anode.

The relationship between the final speed of the electrons and the anode voltage is mathematically expressed as

$$V = 593 \times \text{SQR}(E_b) \quad (\text{km/s})$$

where V is the final speed of the electrons and E_b is the anode voltage.

If the anode voltage is 10 kV, for example, the final speed of the electrons hitting the screen will be around 60,000 km/sec. The electron beam travels with constant speed after passing through the high-voltage anode.

To sum up: the electron gun performs several functions. It first produces the electron beam. The control grid controls the amount of the beam, the accelerator grid speeds it up and the focus grid converges it to the smallest possible spot on the screen.

The electron beam has to produce a raster. A raster is the rectangular area scanned by the beam as it is deflected horizontally and vertically. The beam is turned aside electromagnetically by the deflection coils mounted outside the neck of the CRT. These coils are called the yoke. Sawtooth currents are supplied to the deflection coils, producing a varying electromagnetic field that deflects the beam horizontally and vertically.

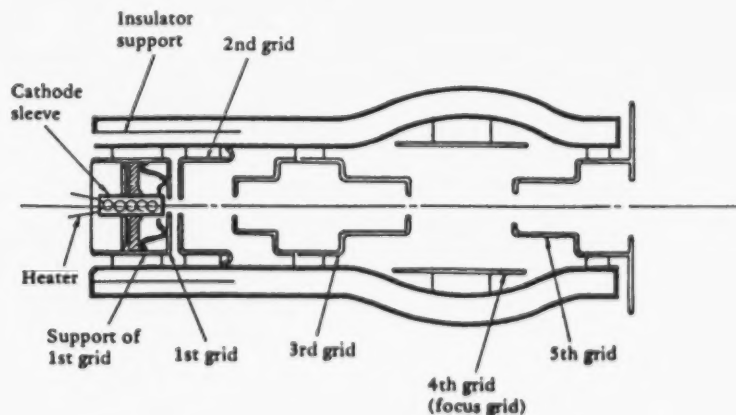


Figure 5-2
A typical electron gun

The electron gun and the electron beam

Figure 5-2 illustrates a typical electron gun. Note that the cylindrical metallic electrodes are arranged in series on one axis. The major parameters that determine the operation of the CRT are a) the length of the electron gun, b) the diameter of the cylindrical electrodes, c) the distances between electrodes and d) the voltages of individual electrodes.

The cylindrical electrodes are referred to in terms of their position relative to the cathode. This means that G1 is the electrode nearest the cathode, G2 the second nearest and so on.

Emission of electrons from the cathode. The cathode is coated with a special substance consisting of barium oxide, designed to emit electrons when heated to around 800 degrees centigrade. (See Figure 5-3).

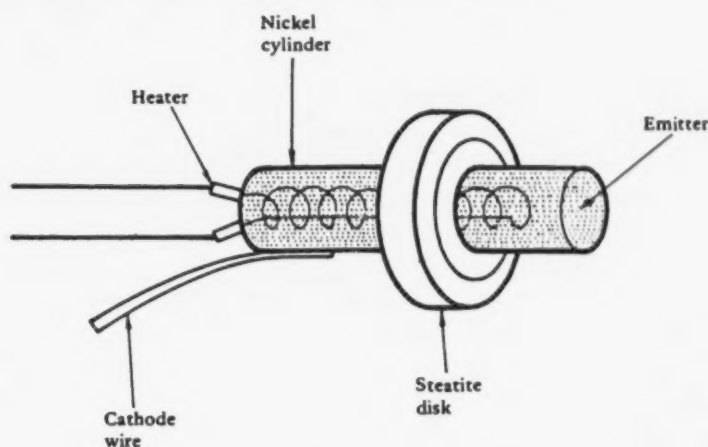


Figure 5-3
Heater and cathode assembly

Modulating the electron beam. The bias voltage of the CRT is the voltage between the cathode and the control grid (G1). The amount of electrons emitted by the cathode is controlled by the bias voltage. The bias voltage can be increased by raising the G1 voltage (G1 voltage becomes more negative) while keeping the cathode voltage constant, or by increasing the cathode voltage (cathode voltage becomes more positive) while keeping the G1 voltage constant. By varying the bias voltage, one controls the amount of emitted electrons. As the bias voltage is increased, the control grid allows less electron flow because electrons carry negative charges, which are repelled by the negative voltage of G1. For the same reason, the control grid allows greater electron flow as the bias voltage is decreased. In this discussion, the cathode is set as the reference voltage. Hence when we say that the G1 voltage is "negative," the actual voltage of G1 is less than the actual voltage of the cathode with respect to the ground.

Generally the brightness of the phosphor screen is proportional to the intensity of the electron beam. Since the bias voltage can control the amount of electrons emitted from the cathode, this voltage can control brightness of the phosphor screen. Hence the amount of the electron beam is varied by changing

the video signal applied to G1 or to the cathode. This process is called *modulating the electron beam*. If the video signal is applied to the cathode, the modulation of the beam is called the cathode drive. If the video signal is applied to the control grid, it is called the grid drive.

In the grid drive the G1 voltage changes only with respect to the cathode. In the cathode drive the voltage of the cathode varies. Since the cathode is the reference voltage of the electrodes, the individual voltages of each electrode are affected. The cathode drive is commonly used in modern television receivers.

The amount of electron emission is significantly controlled by the voltage drop between the cathode and G1 (the bias voltage). Nevertheless the voltages at G2 and G3 relative to the cathode also affect the amount of the electrons emitted.

General characteristics of a CRT

The electrical characteristics of a CRT depend mainly on the characteristics of the electron gun. These characteristics will be taken up in the following discussion.

Cut-off voltage When the bias voltage is increased, the amount of the electron beam becomes less. The value of the bias voltage such that no electrons strike the phosphor screen (no visible raster) is called the cut-off voltage. This cut-off voltage is denoted by E_{co} .

There are two ways of measuring the cut-off voltage. One is to set the cathode voltage as the reference voltage and adjust the G1 voltage such that the raster is barely visible. The voltage is then measured at G1 with respect to the cathode. This voltage is negative and is called the grid cut-off voltage (E_{c1co}). Another is to set the G1 voltage as the reference voltage and adjust the cathode voltage until the same condition is satisfied. The cut-off voltage is then measured at the cathode with respect to G1. This voltage is positive and is called the cathode cut-off voltage (E_{kco}).

Generally the cut-off voltage lies between -30 and -80 V for black-and-white CRTs and between -50 and -100 V for colour CRTs. This value is measured at G1 with respect to the cathode. The value of the cut-off voltage usually differs even among CRTs of the same size, type and brand. Increasing G2 voltage (E_{c2}) raises the cut-off voltage.

Cathode emission. The intensity of the electron beam produced by the electron gun depends on the structure, shape, size and substance used for the cathode. The amount of the beam is also related to the value of the cut-off voltage. The value of cathode emission is the cathode current (I_{ko}) at zero bias. Zero bias means the cathode voltage is equal to G1 voltage. This cathode current is related to the cut-off voltage (E_{co}) according to the following formula:

$$I_{ko} = A \times (E_{co})^{3/2} \dots \dots \dots 5.1$$

where A depends on the structure of the electron gun and the substance used for the cathode. A is called the *perveance*, or the ability of the cathode to emit electrons. For CRTs with the same cut-off voltage, a CRT with a greater perveance

produces an intense electron beam; thus a smaller driving voltage is required. With this kind of electron gun, the G2 voltage (E_{c2}) can be lower, ranging from 40 to 100 V, than the usual values of about 400 V. This high-perveance gun is used especially in CRTs of cathode-drive TVs and in small CRTs of small screen solid-state TVs.

Current characteristic and gamma. The relationship of the bias-voltage and the electron beam current is shown in Figure 5-4(a). Plotted on the horizontal axis is the drive voltage E_d . E_d is the variation of the G1 voltage from the cut-off voltage (E_{c0}) towards a value such that the beam current increases.

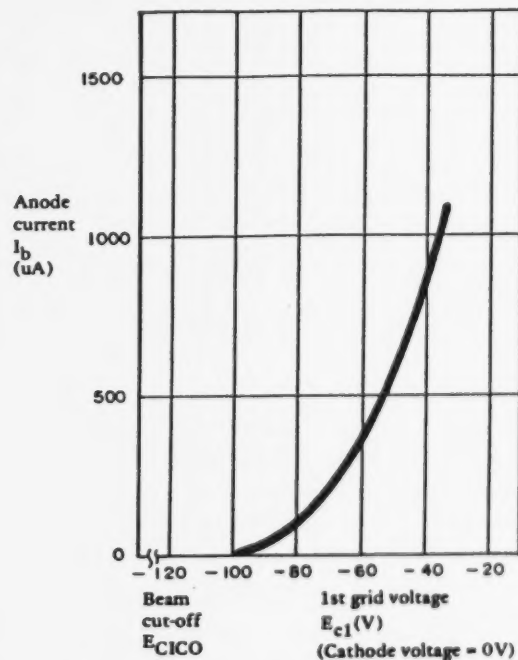
The relationship between E_d and I_b is called the *drive characteristic*. From the theory of static electricity the drive characteristic is expressed mathematically as

$$I_b = KE_d^{\gamma} \quad \dots 5.2$$

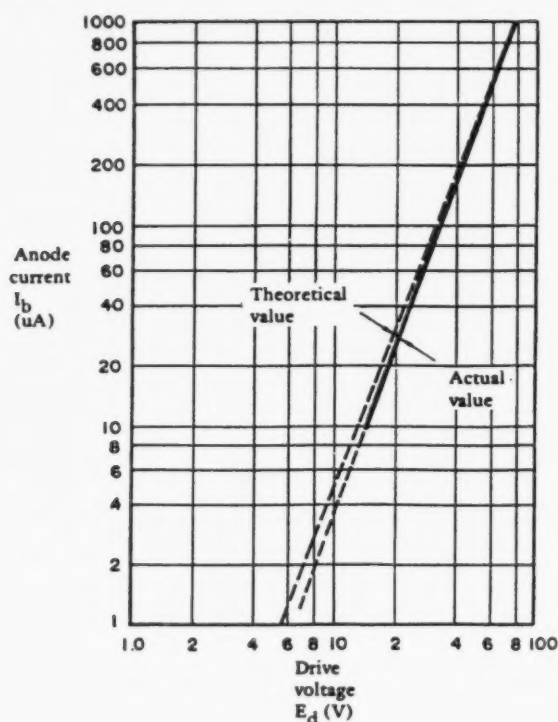
The graph in Figure 5-4(b) is expressed in logarithmic scales to illustrate clearly the relationship expressed by equation 5.2. The slope of the drive characteristic curve in Figure 5-4(b) is called *gamma*. When getting the value of the cut-off voltage in a dark room, gamma for a 20-inch colour CRT is around 2.5 to 3.

Focus. 1) Methods of focusing the electron beam. One must focus the electron beam to converge it to the smallest possible spot on the phosphor screen.

Figures 5-5(a) and (b) show the arrangement of the electrodes of the electron gun and the electron beam, respectively. In (b) the electron beam is initially focused by an electromagnetic field near the electrodes. This field converges



(a) Current characteristic for (19") CRT



(b) Drive characteristic

Figure 5-4
Characteristics of a CRT

the beam to a point near G1 and G2. This point is called the *cross-over point*. Since electrons repel each other, the beam diverges as it travels away from the cross-over point. Therefore the electron beam must be focused again and the need for a main convergence lens arises. This lens is an electronic lens that converges the electron beam on the phosphor screen. Its function is similar to an optical lens used to focus light rays.

There are two types of main convergence lenses: static and dynamic. The static convergence lens is a cylindrical electrode. The beam is focused by the electric field produced by the voltage applied to the cylindrical electrode. The dynamic convergence lens is a permanent magnet or a convergence coil mounted outside the neck of the CRT. The beam is focused by the magnetic or electromagnetic field produced by the magnet of the convergence coil. Black-and-white TV sets normally use the static convergence lens.

There are two kinds of electron lenses in the static convergence system. One is the uni-potential lens, the other the bi-potential lens as shown in Figure 5-6. Table 5-1 compares the corresponding characteristics of these two kinds of lenses. The uni-potential lens is used in black-and-white and small colour CRTs, the bi-potential lens in medium (18-inch) and big colour CRTs.

Table 5-1
Comparison of static lens

Type Item	Uni-potential	Bi-potential
Focus voltage	-100 to 400V	around 5kV
Size of focused spot on screen	large	small
Change of focus on different scenery	small	large
Focus on the corners of screen	small	large
Focus voltage	+B voltage	High voltage used in horizontal deflection circuit

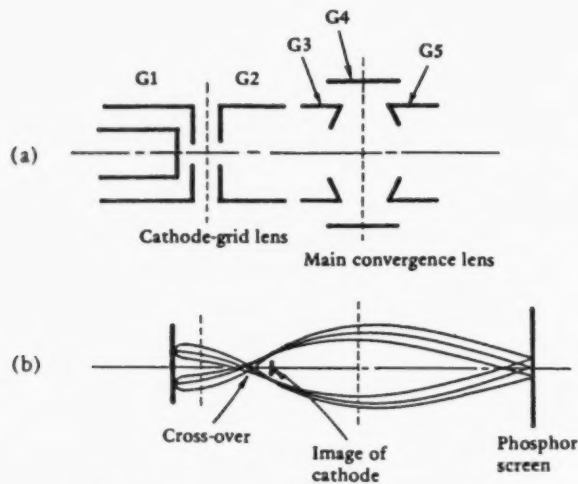


Figure 5-5
Electronic lens and beam convergence

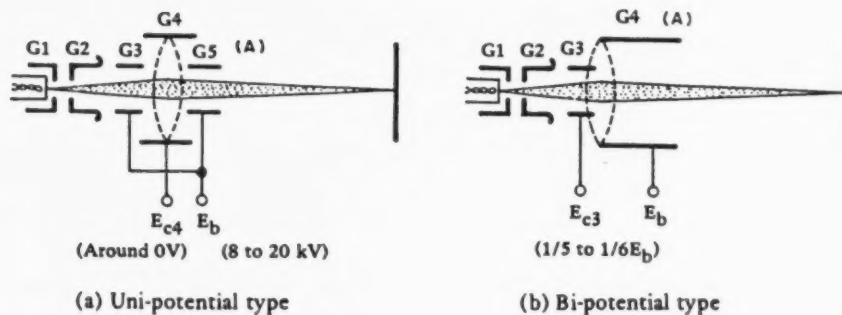


Figure 5-6
Static beam convergence

2) Focus characteristic of the CRT (sharpness and resolution). The focus characteristic of a CRT is generally evaluated by the clear distinction (resolution) of each line in the wedge pattern of a standard test. However, this alone is not a complete evaluation. Usually, even though the resolution of the lines is good, the sharpness of the lines is poor. That is, the lines are not well focused. Poor sharpness results in poor contrast, which is evident in the smaller elements of the picture.

The effect of this high-resolution, low-sharpness quality is demonstrated using the dot patterns on the screen. Careful observation will reveal a halo around the dots. This halo is usually generated by a defective electronic lens (aberration of the lens) or by a lower than normal voltage applied to the lens. The halo effect is shown in Figure 5-7(b). Figure 5-7(a) shows the ideal dot and Figure 5-7(c) an expanded dot. The expanded dot is caused by a higher than normal voltage applied to the electronic lens.



Figure 5-7
A faceplate dot lighting

The phosphor screen

The screen is a thin coating of fine phosphor crystals that emit light when hit by electrons. A very thin coating of aluminium is also applied to the phosphor screen. This coating is called the *metal back*.

Phosphor screen materials. The phosphor substance consists of very fine crystal particles that emit light when bombarded by high-velocity electrons. The diameter of these particles is a few microns (a micron is one millionth of a metre). There are many types of substances developed for the phosphor screen.

For colour CRTs, different substances are used. For the red phosphor, rare earth elements such as yttrium and europium are used. Zinc sulfide, mixed with a small amount of silver, is usually used for the blue phosphor; a mixed sulfide of copper and aluminium is used for the green phosphor.

The white phosphor of the black-and-white CRTs is an even mixture of the blue phosphor and the yellow phosphor (which is a mixed sulfide with a small amount of silver).

Metal back (aluminised screen). As shown in Figure 5-8, the phosphor screen is covered with a fine aluminium coating called the *metal back*. This metal back is connected to the high-voltage anode of the CRT. Its thickness is usually between 0.1 and 0.3 microns. Since the metal back is so thin and the electrons so small, the electron beam can easily penetrate it. Including the metal back has the following advantages.

- 1) It eliminates voltage drop between the screen and the cathode.

Electrically, the phosphor screen is an insulator. When electrons hit the phosphor screen, negatively charged electrons pile up on the screen and create a negative space charge. This charge will repel or slow down the electron beam.

In effect, the brightness of the screen does not increase the anode voltage. But if the metal back is included, the electrons accumulated on the screen are absorbed by the metal back because the anode is connected to it through the graphite coating called the aquadag. Thus there will be no voltage drop between the anode and the screen, because the metal back is shorted to the anode by the aquadag.

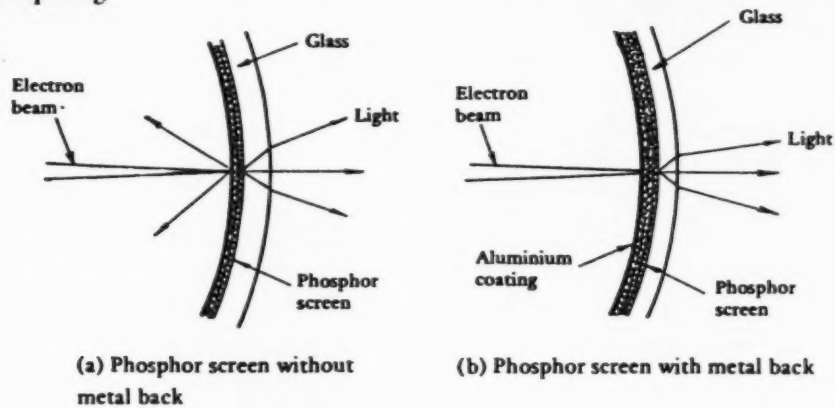


Figure 5-8
Metal-back screen

2) It doubles the brightness.

When the phosphor is hit by the electron beam, it emits light towards both the faceplate and the electron gun. With the metal back attached, light emitted towards the electron gun is reflected towards the faceplate. Therefore the brightness is increased by around 100 per cent.

3) It prevents ion spots.

Even though the CRT is a high-vacuum tube, some gas particles remain inside the tube and are ionised by the electron beam. The resulting ions accelerate towards the screen. They have low velocity and are heavy, so they are not turned aside by the deflection coils and travel straight towards the centre of the screen. If these ions are allowed to hit the screen continuously, the phosphor coating will be damaged. The ions burn the screen and the burned spot is called an *ion spot*. This spot is dark grey and becomes permanent. However, the ions are much bigger than the electrons, so they cannot penetrate the metal back as the electrons can. Thus the metal back prevents ion spots.

Characteristic of light emission. The brightness (B) of the phosphor screen depends on the anode voltage (E_b , kV), beam current (I_b , mA), screen size (S , square metre), glass-plate transparency (T_f) and the ability of the phosphor to emit light. Within the permissible values of E_b (less than 25 kV) and the maximum value of I_b , the brightness (B) of the screen can be expressed by the formula below,

$$B \propto k (E_b - E_0) \cdot I_b \cdot T_f / S \quad \dots 5.3$$

where E_0 depends on the thickness of the phosphor and the aluminium coating and is usually around the 3 to 5 kV. K is a constant related to the ability of the phosphor screen to emit light. In black-and-white CRTs where B is expressed in ft-L, k is between 5 and 7.

As shown by the graph in Figure 5-9, the brightness is proportional to the electron beam current. However, the brightness can saturate at higher currents. When the brightness is saturated, it will not account for any further increase in the beam current.

Another important light-emission characteristic of the phosphor screen is its persistence. After being hit by electrons, the phosphor screen emits light. This light gradually fades or fluoresces after a short time. If this fluorescent effect takes place within a considerable period, the screen will show a trailing or smeared picture. Persistence is the time it takes the phosphor to fade to one tenth of its original brightness.

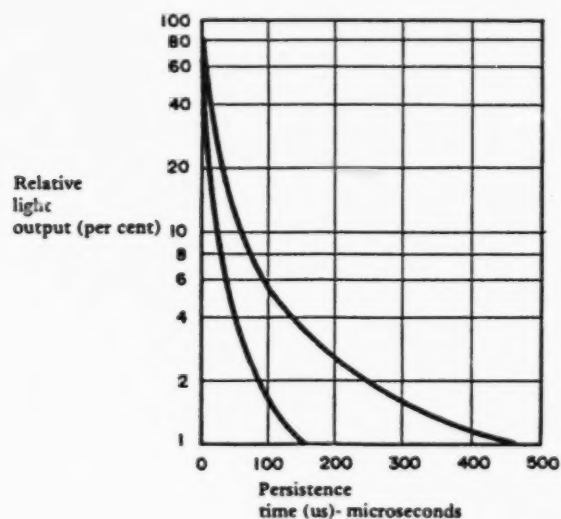


Figure 5-9
Persistence of a black-and-white CRT

The widely used phosphor sulfide in black-and-white CRTs and the green and blue phosphors of the colour CRTs have a persistence time of between 30 and 100 microseconds. The rare earth elements used for the red phosphor of the colour CRTs have a persistence time of approximately 1 millisecond. This long persistence poses no problem in practical applications.

Contrast ratio and the transparency of the faceplate. The quality of the picture depends on the contrast ratio. The contrast ratio is the ratio of the brightness of the bright peak, or white-level luminescence, to the brightness of the dark peak, or black-level luminescence. The contrast ratio should be at least 20:1. However, a ratio of 30:1 or greater is desirable for a better picture.

In usual viewing conditions (watching TV in a bright room), the surface of the CRT screen reflects external room light. This light mixes with the light emitted by the phosphor screen; thus the portion of the screen which should be

black does not appear as dark as it should. This lessens the darkness or increases the black-level luminescence, causing a smaller contrast ratio. If, for example, the brightness of the white-level and the black-level luminescence were 45 ft-L and 1 ft-L, respectively, without external light reflection, the contrast ratio would be 45:1. However, if we consider the reflection of the external room light and assume it to be 3 ft-L, resulting contrast ratio will only be 15:1. The decrease in contrast ratio due to the external room light can be compensated by placing a filter on the faceplate of the screen. Let us analyse what happens when a filter, say with 50 per cent transparency, is placed on the faceplate.

This filter will reduce the brightness of the white-level luminescence by 50 per cent, making it 22.5 ft-L. Consider the effect of this filter on the reflected room light. Before the external room light reaches the surface of the faceplate, it is reduced by the filter to 50 per cent, making it 1.5 ft-L. After it is reflected by the faceplate, the room light is again reduced by the filter to 50 per cent, making the final value of the external room light 0.75 ft-L. When we take the ratio of the white-level luminescence to the black-level luminescence, 22.5 ft-L over 0.75 ft-L, the contrast ratio improves from 15.1 to 30.1. Thus although the filter reduces the brightness of the screen, the contrast ratio improves.

The faceplate of black-and-white CRTs is a dark-tinted glass, the faceplate of colour CRTs is a clear glass with 85 per cent transparency. A clear glass is used for colour CRTs, since its contrast ratio is improved by the black matrix phosphor screen.

The life span of the CRT and some technical details

The life span of the CRT. The life span of the CRT is approximately 10,000 hours. Assuming that the TV set is used for about 2,000 hours a year (a normal average of approximately five hours a day), then the life span of the CRT is practically around five years. The principal factor which determines the life span of the CRT is the ageing of the cathode, which is caused by the remaining gas particles inside the CRT.

A chemical reaction occurs between the coating of the cathode and the ions produced when these gas particles are ionised by the electron beam. This reaction corrodes or ages the cathode. The ageing of the cathode decreases its efficiency in electron emission. A decrease in electron emission causes a raster and a picture that cannot be made bright enough.

A typical symptom of ageing is the considerable time it takes for the CRT to warm up. The weak electron emission of the cathode can be temporarily remedied by increasing the heater or filament voltage. A small, multi-tapped filament transformer is used to increase the heater voltage, but this is hard to do with TVs without power transformers. Increasing the filament voltage also shortens the life span of the cathode. An excessive increase in the filament voltage causes blooming in the picture. Thus the only practical remedy for weak electron emission is to change the CRT.

Implosion protection. Since the CRT is a high-vacuum tube and has a large surface area, the force exerted on it by the atmospheric pressure is great. Hence, because of its inherent structure, there exists a danger of implosion (inward explosion). When a CRT implodes, the glass envelope shatters and its fragments are

sucked inwards because of the negative pressure inside the CRT. After imploding, the tube explodes. In the past, a thick safety glass (about 10 mm) was placed in front of the CRT screen to protect the viewer from implosion. However, this has its drawbacks. The safety glass reflects external light, decreasing the contrast ratio. It also increases the weight of the CRT. Furthermore, fine dust particles accumulate between the CRT screen and the safety glass and these are very difficult to remove.

For these reasons, modern CRTs use a mechanical support to minimise the danger of implosion. These CRTs with integral-implosion protection features are called *implosion-proof CRTs*. There are two types of implosion protection used: the tension-belt type and the bonded type. (See Figure 5-10.)

X-rays in colour CRTs. X-rays are generated whenever high-velocity electrons hit metals. When the anode voltage is high enough (greater than 16 kV), X-rays are generated when high-velocity electrons strike the metal shadow mask. The amount of X-rays is proportional to the value of the anode voltage of the electron gun. Hence a special glass bulb which absorbs X-rays is used for big colour CRTs.

All TV receivers are designed to meet the international safety standard which limits the level of X-rays to less than 0.5 milli-Roentgen per hour (mR/hr) measured five centimetres away from any surface of the receiver.

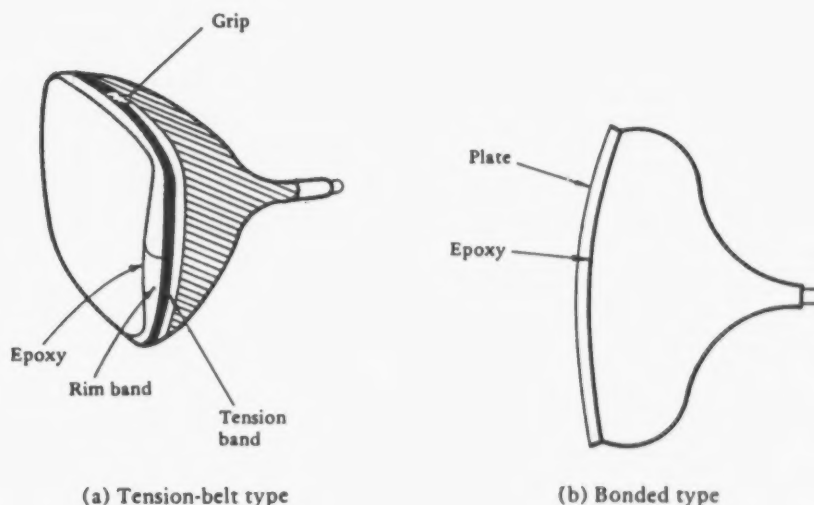


Figure 5-10
Implosion-protection implemented CRTs

The classification and coding of picture tubes

Cathode-ray tubes commonly used in TV sets have a rectangular screen. In black-and-white CRTs the diagonal of its screen measures from 2 to 23 inches; in colour CRTs, from 5 to 26 inches.

Characteristics of black-and-white CRTs:

- a Except for the small CRTs (i.e. tubes with screen diagonal less than 10 inches), the deflection angles are usually 110 or 114 degrees.
- b Dark-tinted glass plates are commonly used for the faceplate.
- c The diameter of the neck is around 29 mm for bigger CRTs; 20 mm for medium and smaller CRTs.
- d Protection from integral implosion is ensured.

Characteristics of colour CRTs:

- a The deflection angle is usually 90 or 110 degrees. (Some colour CRTs use 114 degrees.)
- b A clear glass plate (85 per cent transparency) is used for the faceplate of the black matrix TV screen.
- c The diameter of the neck is from 29 mm to 36.5 mm.
- d Protection from integral implosion is ensured.

Short CRTs use wide-angle deflection while longer CRTs use small-angle deflection because the electrons in longer tubes have more time to be deflected than the electrons in the shorter tubes. A large deflection angle can be obtained by supplying more power to the deflection circuit. CRTs with large deflection angles have a smaller neck diameter so that the deflection coils can be placed as close as possible to the electron beam. This enables a stronger magnetic field to act on the electron beam.

For 20-inch colour CRTs the effective area of the screen is 30 cm by 40 cm. The length for CRTs using a 90-degree deflection angle is around 44 cm; for CRTs using a 110-degree deflection angle it is around 37 inches.

The classification of CRTs registered under Japan Electronics Industries Association is shown in Table 8-2. Note that the CRTs are categorised according to their bulb size (diagonal length of the screen), their registration number and the phosphor material used.

Table 8-2
Classification of CRTs

	Unit used for measuring CRT faceplate diagonal	Registration code	Phosphor
Japanese	mm	alphabetical	Black-and-white B4
			Colour B22
American	inches	alphabetical	Black-and-white P4
			Colour P22

Example:

Japanese 310GNB4 (12 inches B/W CRT)
 310GNB4A (Modified version of 310GNB4)
 510DXB22 (20 inches colour CRT)

American 19GYP22

Basic structure and principles of the colour picture tube

The principal structure and function of a shadow-mask colour CRT

There are several designs of colour picture tubes. Figure 5-11 shows three. There are three patterns in the printing of the phosphor screen: a) dotted, b) vertical-slotted and c) vertical-striped. For each pattern are different shadow masks. These shadow masks have holes of different shapes: a) round, b) slotted and c) vertical-striped. Sony Trinitron colour CRTs use the striped pattern for the phosphor screen printing and, consequently, the shadow mask with vertical-striped holes. This shadow mask is called the aperture grille.

Although these shadow masks differ in the shape of their holes, they have the same function. Therefore we will refer to any of them as a shadow mask.

The shadow mask is a thin metal plate (about 0.15 mm) mounted inside the colour CRT 10 mm away from the phosphor screen. It contains 200,000 to 400,000 tiny round holes arranged in rows (500 to 200 vertical-striped holes for aperture grille types). Each hole has a diameter of 0.20 to 0.25 mm. These holes are evenly spaced with a distance of 0.56 to 0.75 mm. For each hole in a shadow mask, there is a corresponding trio of red, green and blue phosphor dots. Only 15 to 20 per cent of the electron beam passes through the mask.

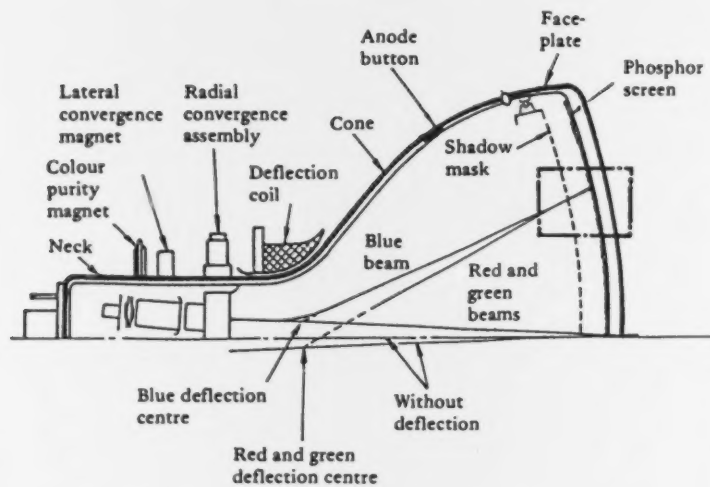
There are two types of electron gun arrangements in a colour CRT: the delta gun and the in-line gun. Figure 5-11(a) shows the delta gun arrangement. The three guns are positioned to form the vertex of an equilateral triangle. In the in-line arrangement, as shown in (b) and (c), the electron guns are placed side by side in a horizontal or a vertical plane. The horizontal arrangement of the in-line gun is more widely used.

The three electron beams radiated by the three electron guns are turned aside by the deflection coils to scan the phosphor screen. But these beams are blocked by the shadow mask. The phosphor screen emits light only when it is hit by electrons that pass through the holes of the shadow mask. The beams should hit only their corresponding colour phosphor dot or stripe. Therefore the colour CRT should be so designed that the deflection centre of each electron beam (see Figure 5-12), the centre of every individual hole and its corresponding phosphor dot or stripe form points in a single imaginary straight line.

As the electron beam is modulated by the luminance and the chroma signal, every set of phosphor dots (red, green and blue) will emit red, green and blue lights according to the colour information in the chroma signal for the reproduction of almost all colours.

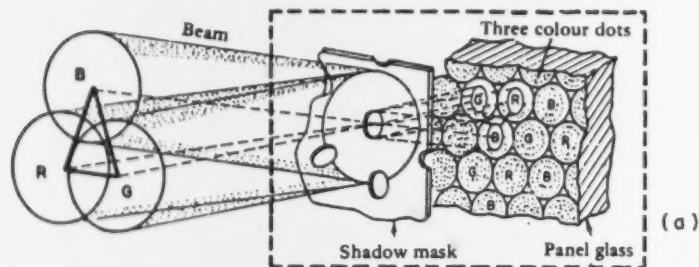
Production of three primary colours and colour purity

The colour CRT screen is formed by roughly one million sets of red, green and blue phosphor dots. This immense number of closely, yet evenly spaced, phosphor dots on the screen is possible because of high printing technology. In filling the screen with these dots, it was assumed that the paths of the deflected electron beams were similar to the paths of the light rays from a spotlight placed in the deflection centre of the electron beams, while the phosphor material for each colour is developed or applied to the screen.

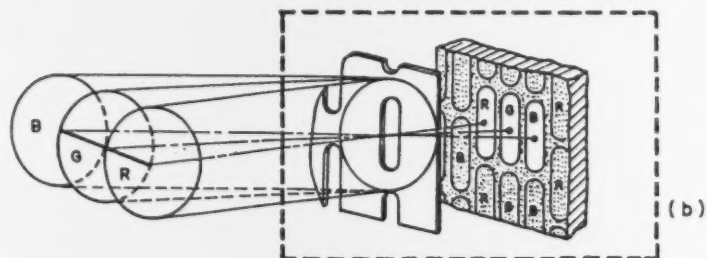


The following figures are the magnification of the square area shown in the above figure.

(a) Round shadow mask and phosphor screen in delta gun



(b) Slotted shadow mask and phosphor screen in in-line gun



(c) Aperture grille-shaped shadow mask and phosphor screen

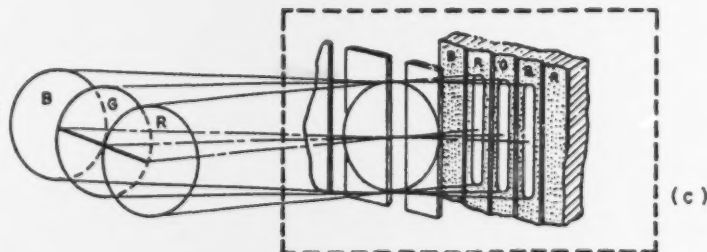


Figure 5-11
Structure of a shadow-mask colour CRT

In setting the phosphor material for the red electron beam, the screen is first evenly coated with red phosphor mixed with other chemicals that make it insoluble in water after exposure to light. Then the shadow is set in place and a spotlight is placed at the deflection centre of the red electron beam. The light is turned on and the part of the phosphor coating uncovered by the holes of the shadow mask is exposed to light. After exposure, the shadow mask is removed and the screen immersed in water. The exposed part of the coating remains on the screen while the rest is dissolved. Since the spotlight was placed in the deflection centre of the red electron beam, the remaining phosphor material on the screen is the phosphor dots or stripes for the beam. Thus it is assumed that this beam will hit only this phosphor material. The same principle is used in developing or printing the blue and green phosphors on the colour CRT.

The phosphor dots on the screen are very close to each other, making the design of the shadow mask very critical. The distance between the holes of the shadow mask, the distance between the shadow mask and the phosphor screen, and the radius of the curvature of the shadow mask should be precise. Also, the electron guns should be so arranged that the deflection centre of each beam will coincide with the spotlight used for developing the phosphor for each particular beam. This is necessary to enable the beams to hit only their respective phosphor material. It is also necessary for these beams to converge at the shadow-mask holes. However, because of the complicated manufacture of CRTs, it is very difficult to produce CRTs with precision.

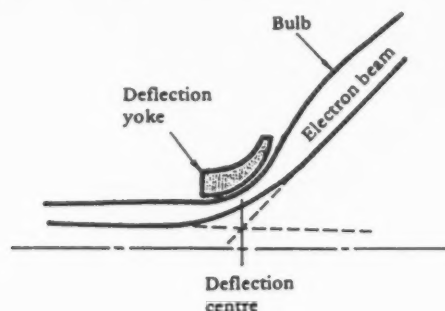


Figure 5-12
Deflection centre

To compensate for the slight errors in manufacture, several adjustment mechanisms and accessories are included and they are discussed in the following sections.

Colour purity adjustment. This adjustment is necessary to make the three electron beams (R, G and B) hit only their respective phosphors so that reasonably pure red, green and blue rasters may be produced. In conventional TVs this can be done by sliding the deflection yoke along the neck of the CRT or by adjusting the colour purity magnets (also called the beam landing magnets) that slightly bend the path of the electron beams.

Good colour purity is indicated by pure or solid red, green and blue rasters; poor purity, by colour patches usually at the corners of the screen.

Deflection yoke. In modern in-line colour CRTs the deflection yoke, together with several adjustment magnets which are adjusted with precision during the production stage, is mounted permanently on the neck of the CRT to avoid changes in their characteristic because of vibrations during transport. In this manner the deflection yoke, the other adjustment magnets, and the CRT are considered one whole component.

Degaussing coil. Another important factor that affects colour purity is the presence of external magnetic fields such as the earth's magnetic field. The earth's weak magnetic field is relatively strong enough to affect the path traversed by the electron beams to the CRT screen.

To minimise or counteract the effect of external magnetic fields, a steel cover is generally attached to the cone of the CRT to shield external magnetic fields. However, the shadow mask of the colour CRT is magnetised by the earth's magnetic field. The degaussing coil is used to demagnetise the shadow mask.

In degaussing a TV receiver, one applies a decaying AC current to the degaussing coil. In the process, the decaying current produces a strong decaying magnetic field that demagnetises the shadow mask.

The principle of convergence

Occasionally, in multi-colour printing as in colour magazines, when two or more objects or parts of an image have different colours the edges or borders of their colours overlap. This results in poor colour print. When the beams do not hit their respective phosphor dots in colour CRTs, colour fringing occurs at the edges of the objects or parts of an object with different colours in the picture. This can be prevented by letting the three electron beams intersect in every hole of the shadow mask. The intersection of the three electron beams is called *beam convergence* or, simply, *convergence*. One gets good colour reproduction if the three electron beams converge in every hole of the shadow mask.

There are two types of convergence: static and dynamic. Static convergence is the convergence of the three electron beams before they are turned aside by the deflection coils. Dynamic convergence is the convergence of the three electron beams while they are turned aside by the deflection coils. Improper static convergence causes an even degree of colour fringing all over the screen. This is caused by the misalignment of the three electron guns during manufacturing. This can be compensated by the static convergence adjustment.

In improper dynamic convergence, the degree of colour fringing varies at different parts of the screen. The fringes are more pronounced at the edges, particularly at the corners of the screen, because even if the three electron beams are converged in the centre of the screen, the electron beams slightly diverge from each other when they are deflected, as shown in Figure 5-13. Colour fringing is slightly compensated by the precise windings of the deflection coils. In the delta gun assembly, no matter how precise the windings of the coils, colour fringing is not totally eliminated. Thus the need for dynamic convergence.

However, the coils are wound in such a way that dynamic convergence adjustment becomes easier. In the in-line gun assembly a precisely wound coil performs the function of the static convergence adjustment. Thus static convergence adjustment is unnecessary. In the static convergence of the delta gun,

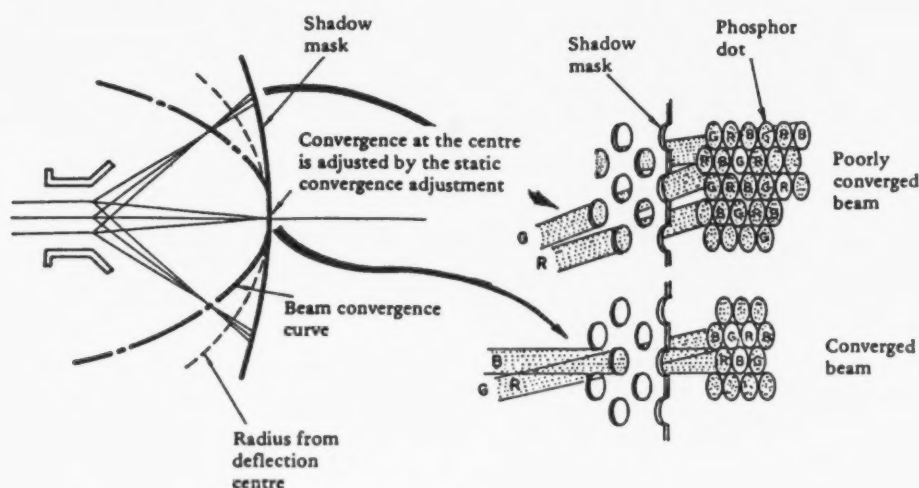


Figure 5-13
Poor convergence at the edge of the screen

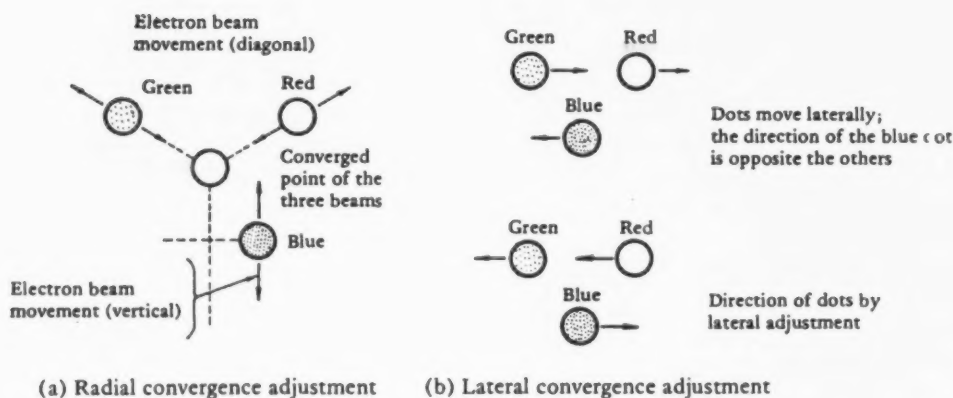


Figure 5-14
Colour dots movement of delta gun

the radial convergence adjustment deflects the electron beam radially from the centre [see Figure 5-14(a)] and the lateral convergence adjustment moves the electron beams sideways (in most cases only the blue beam is able to move sideways). Dynamic convergence adjustment is usually done only by radial convergence adjustment. For the in-line gun, the convergence adjustment is done by changing the direction of the beams laterally, as shown in Figure 5-15.

Production of colours on the phosphor screen and white balance

As described earlier, the phosphor dots or stripes on the screen are very small. It is difficult to identify the individual coloured lights emitted by each coloured

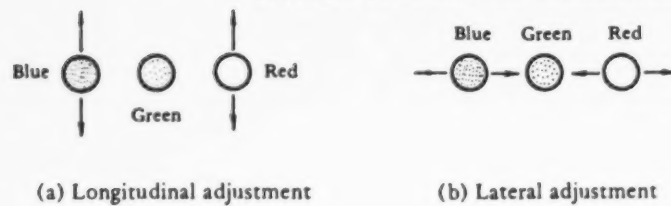


Figure 5-15
Beam convergence of in-line gun

phosphor. What the eye perceives as a multi-coloured picture is actually composite colour with discrete red, blue and green components. Almost all colours can be reproduced by properly controlling the intensity of the three electron beams to yield the proper proportion of the three primary colours, which are red, green and blue.

At TV broadcast stations the colour of the object is separated into its three primary colours by an optical filter inside the camera. The red, blue and green chroma signals are produced in proportion to the object's colour.

Colour TV receivers have to reproduce the chroma signals properly. When the standard white signal is transmitted by the TV station, the TV receiver should be adjusted to reproduce the same signal at all levels of brightness and contrast. This is called *white-balance adjustment*.

The ratio of the three electron beams to produce a standard white signal, one of the most important standards in the production of colour CRTs, is determined by the colour tone and light-emission efficiency of the phosphors and the definition of the standard white.

The standard white of the NTSC (National Television Standard Committee) transmission is the white colour produced by sunlight (colour temperature roughly around 6500°K). Therefore the standard white of the colour CRT at the time of adjustment of the white balance should be set to the white colour produced by the sun. Nevertheless, considering human colour preference, the standard white used at the colour CRT is set at a little higher colour temperature (bluish white at about 9300°K). Hence the beam current ratio shown in specifications of the picture will produce a white raster with this colour temperature.

Kinds of colour CRT and their general characteristics

Structure of electron guns

The basic structure of electron guns in colour CRTs is similar to the guns in the black-and-white CRTs. This is shown in Figures 5-2 and 5-6. The colour CRT, however, contains three electron guns.

In designing the electron guns for colour picture tubes, the simplicity of the structure and the efficiency of electron emission are always considered. The electron gun structure should be as simple as possible to fit in the small space allotted in the neck of the CRT. But its effectiveness in radiating the electron beam should not be sacrificed. Figure 5-16 shows four types of in-line electron gun structures.

The simplest consists of three independent electron guns, as shown in Figure 5-16(a). Each electron gun has its own cylindrical cathode and separate electrodes G1, G2, G3 and G4. The voltages of the cathode, G1 and G2 of each electron gun are applied separately.

Figure 5-16(b) shows an arrangement where the G1s, G2s, G3s and G4s of the three electron guns are connected to each other. This structure is compact. However, a common supply for the G1s and G2s is not favourable.

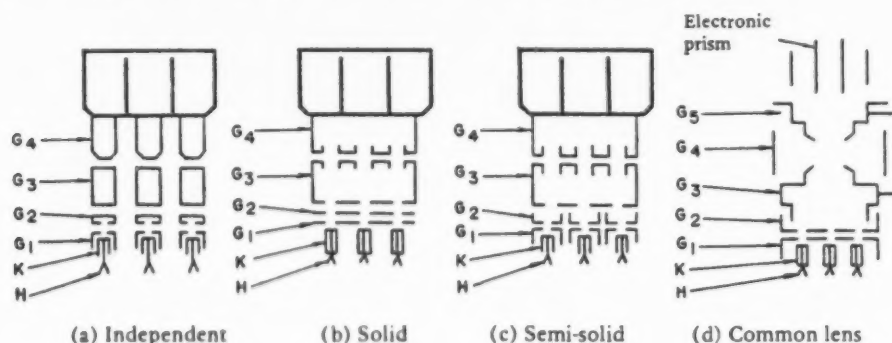


Figure 5-16
Structure of in-line three-beam electron gun

The arrangement shown in Figure 5-16(c) is a composite of the properties of structures (a) and (b). The arrangement shows three electron guns with separate G1s and G2s. The G3s and G4s, however, are connected.

Figure 5-16(d) is the common lens type and has one electron gun with three independent cathodes. The electron beams share the same G1, G2, G3, and G4 electrodes.

As shown in (a), (b) and (c), the bi-potential electrodes G3 and G4 work independently to focus the three electron beams. In (d) the uni-potential electrodes G3, G4 and G5 work together to focus the beams.

The common lens type in (d) is a very compact structure, with the main convergence lens having a bigger diameter, thus possessing more merits than the other structures. However, voltages cannot be applied independently to the electrodes, only to the cathodes.

The characteristics of the colour picture tube

Electrode voltage. Except for the anode, the voltages for the rest of the electrodes are supplied to the base pins. The configuration of the base pins differs in every type of CRT and it is advisable to refer to the CRT manuals for the correct configuration.

The anode is also connected to the aquadag coating (conductive graphite coating) inside the CRT, the shadow mask and the metal back (aluminium coating) of the phosphor screen. The anode voltage (E_b) is supplied through the anode button on the cone of the CRT. E_b is around 16 to 20 kV for small and medium colour CRTs and 23 to 25 for large colour CRTs.

For the bi-potential CRTs the voltage of the focus electrode G3 is about one fourth or one sixth of the anode voltage. This voltage should be adjusted to get the best focus. For the uni-potential CRTs, G4 is usually the focus electrode. The focus voltage applied to G4 can be adjusted within the range of 0 to 400 V.

The voltage of the second grid (also called the *screen grid*) is set between 200 and 600 V with respect to the cathode to adjust the white balance. The filament voltage is generally 6.3 V AC. The filament current ranges from 0.3 to 0.9.

Modulation and drive characteristics. For the electron gun structures shown in Figures 5-16(b) and (d) where all the electrodes are common except for the cathodes, the three video signals matrixed with red, blue and green are applied to the three independently controlled cathodes. For the electron gun structures shown in Figures 5-16(a) and (c), where each of the three electron beams is controlled by G1 of each electron gun, the Y signal is applied to the cathodes, and each of the colour-subtraction signals (R-Y, G-Y, B-Y) is applied to the G1 of the proper electron gun. The beam cut-off point of the colour CRT refers to the condition when the vertical deflection of the CRT is disabled and the thin horizontal line can no longer be seen by the naked eye. This means that the bias voltage of the CRT is set to the cut-off voltage, and the flow of the beam current is reduced to zero. By setting the cut-off voltage as the reference, the drive characteristic curve of the colour CRT will approximate a straight line if drawn in logarithmic scales, as shown in Figure 5-17.

As shown in the chart, when the beam cut-off voltage is set to a constant value by adjusting the G2 voltage (of the electron gun structure, where we can adjust G2 voltage independently), the gamma of the drive characteristics of the three beams will approach unity. Hence it is easier to perform the white balance adjustment. The drive characteristic varies between each CRT even if they are of the same type, size and brand. An example of tolerance specification is shown in Figure 5-18.

Brightness and contrast. The brightness of the colour CRT screen will be proportional to the amount of electrons the shadow mask has allowed to pass. (Only 15 to 20 per cent of the electron beam passes through the shadow mask.) The brightness can be increased by raising either the anode voltage or the beam current. However, excessive increase in the anode voltage causes more X-ray radiation and excessive increase in beam current blooming. The symptom of blooming was described in the section on "Focus." This symptom will cause some part of the picture, particularly the bright part, to be out of focus. The maximum value for the beam current without blooming varies with different

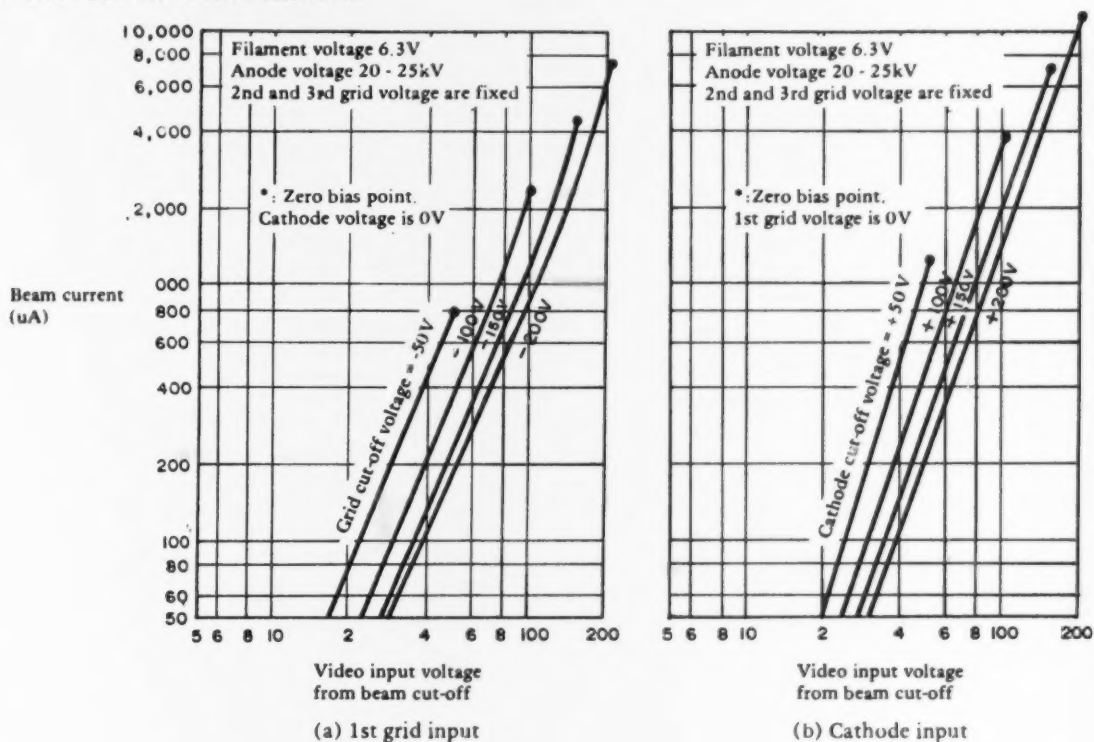


Figure 5-17
Drive characteristic of a colour CRT

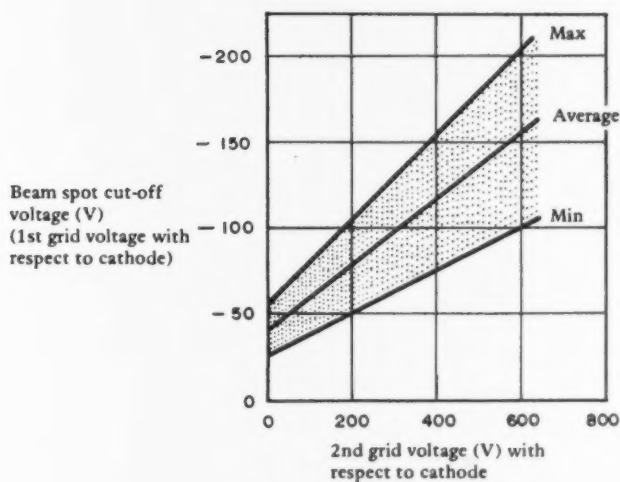


Figure 5-18
Beam cut-off voltage allowance

types of the CRT. The total magnitude of the three beam currents is about 1,200 μA at the time of the white peak. Partial misconvergence of the beams on the CRT screen can occur due to the warping of the overheated shadow mask. To prevent warping, the average value of the beam current (the total of the three beam currents) should be around 700 μA maximum.

The brightness of the colour CRTs is important in the reproduction of the picture. However, picture quality depends more on maintaining a constant contrast ratio even under bright external lights.

The contrast ratio in black-and-white CRTs is improved by using a dark-tinted faceplate for filtering, as previously discussed in the section on "Contrast Ratio and the Transparency of the Faceplate." However, it is not advisable to use a filter on colour CRTs with brightness lower than the black-and-white CRTs because of the low percentage of the beam that passes through the shadow mask. A filter will lessen the brightness so much. The contrast ratio is maintained efficiently by using a black matrix luminescent BML screen.

Compared with the ordinary luminescent screen, the BML screen reduces the amount of reflected external lights to 50 per cent. Therefore, with the use of the BML screen, a relatively clear glass with 85 per cent transparency is used for the faceplate.

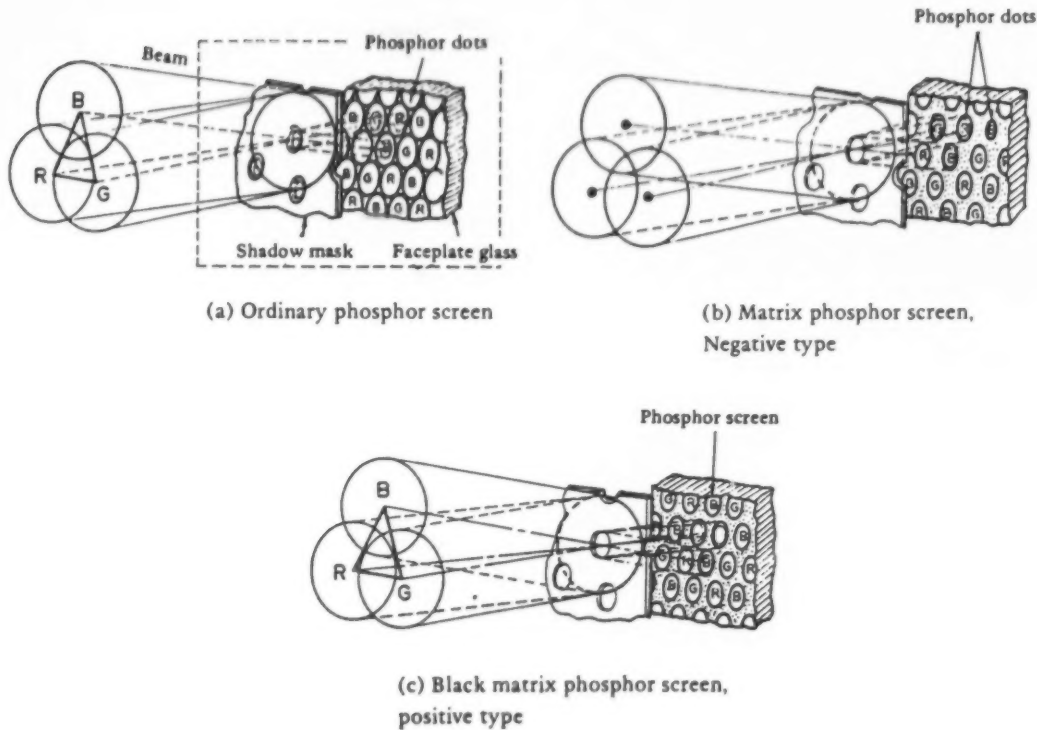


Figure 5-19
Black matrix phosphor screen

Black matrix phosphor screen

As shown in Figures 5-19(b) and (c), the black matrix phosphor screen is made by having gaps painted with a black substance (such as lead) between the phosphor dots on the screen. There are two types of black matrix luminescent (BML) screens: the negative BML screen [see Figure 5-19(b)] and the positive BML screen [see Figure 5-19(c)].

The screen of conventional colour CRTs shown in Figure 5-19(a) contains phosphor dots slightly larger than the holes of the shadow mask. Notice that the diameter of the electron beams hitting the phosphor screen after converging at the shadow-mask hole is equal to the diameter of the holes of the shadow mask, hence smaller than the phosphor dots. Therefore, when only a slight error in beam landing occurs, the beams do not hit the adjacent dots. This reduces colour fringing.

The phosphor dots of the negative BML screen [see Figure 5-19(b)] are smaller than those of the conventional phosphor screen, and the holes of the shadow mask of the negative BML screen are bigger. The diameter of the electron beam in the BML is larger than the diameter of the dots. Since there are gaps between the dots when only a slight error in beam landing occurs, the beams do not hit the adjacent dots. With this kind of screen, the tolerance in the error of beam landing and the effective lighting area is similar to that of the conventional phosphor screen.

However, since the gaps between the dots are painted black, the reflection of external lights compared with the conventional phosphor screen is reduced to 50 per cent. Therefore, with the use of the BML screen, the contrast ratio is improved by as much as 100 per cent without sacrificing colour purity and brightness.

One of the major problems in using the BML screen is the difficulty in getting a pure white raster. In conventional phosphor screens the area of the phosphor dots that emits light is determined by the diameter of the electron beam, not the size of the phosphor dots. Since the diameter of the electron beam is equal to the diameter of the shadow-mask holes, the effective area of the dots emitting light and consequently the amount of light emitted by each dot are similar all over the screen. Therefore the sizes of the phosphor dots on the screen do not have to be exactly the same. In the BML screen, however, the diameter of the electron beams is larger than the diameter of the phosphor dots. Therefore the diameter of the dots determines the area that will emit light and consequently the amount of light. If the sizes of the dots are not exactly the same all over the screen, the intensity of light emitted by each colour phosphor is not uniform throughout the screen. This causes the difficulty in getting a pure white raster. Thus high-precision technology is needed to print the phosphor dots on the screen. A special process is also needed to be able to print dots on the screen with a diameter less than that of the shadow-mask holes.

The diameter of the shadow-mask holes of the positive BML screen is equal to the diameter of the holes of the conventional screen. A positive BML screen can therefore be made by small changes in the production line of conventional colour CRTs.

Quick-start cathode

Solid technology is used in the circuitry of the modern TV receivers. Solid-state components require no warm-up time; they function as soon as power is applied. In TV receivers, however, the CRT is still a conventional vacuum tube that requires warm-up before it operates. It usually takes 20 seconds before a raster is produced. Since 1973 the pre-heating method of the filament has been used to reduce the warm-up time when the power switch is on. Sixty-five per cent of the heater voltage is supplied to the CRT while the power switch is off. This method, however, consumes five to ten watts of electric power.

The quick-start cathode was developed to conserve energy. CRTs with a quick-start cathode will produce a raster on the screen four to five seconds after the power switch is turned on without pre-heating. The structure of the quick-start cathode varies with different makers. However, the following characteristics are common.

- 1 The cathode is smaller, thus heat requirement is less and the heating time is short.
- 2 The filament coil is double-wound to yield a higher heat-generating efficiency.
- 3 The efficiency of heat transfer between the heater and the cathode is improved.

Surrounding parts of the colour CRT

Various components are mounted on the neck of the colour CRT to adjust the direction of the electron beam before it is turned aside by the deflection yoke. The adjustment method can be divided into two: 1) using a permanent magnet (static deflection) and 2) using coils (dynamic deflection).

These surrounding components differ in structure and kind for every CRT. Examples of the delta gun and in-line gun CRTs are shown in Figure 5-20 and Figure 5-21, respectively. In some in-line colour CRTs the dynamic convergence coil is omitted and convergence is done statically.

To counteract the effects of external magnetic fields, a steel cover is placed around the cone of the CRT, and a degaussing coil around the shadow mask. The steel cover shields external magnetic fields while the degaussing coil demagnetises the shadow mask. For black-and-white CRTs the deflection yoke and the centring magnets are the only components mounted on the neck of the CRT.

Deflection yoke. As shown in Picture 3-1, the deflection yoke has specially shaped coils. These coils consist of the horizontal and vertical deflection coils.

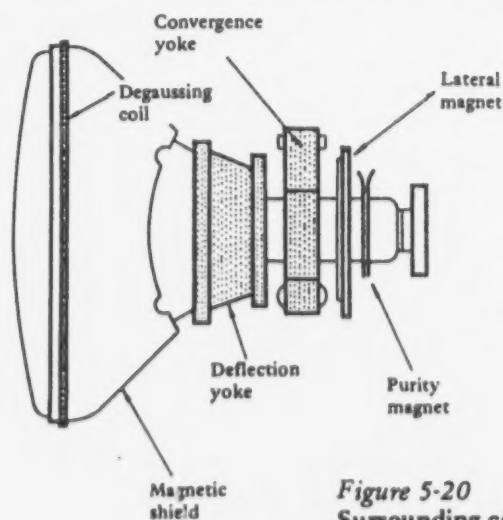


Figure 5-20
Surrounding components
of a delta gun colour CRT

Picture 3-1
A deflection coil

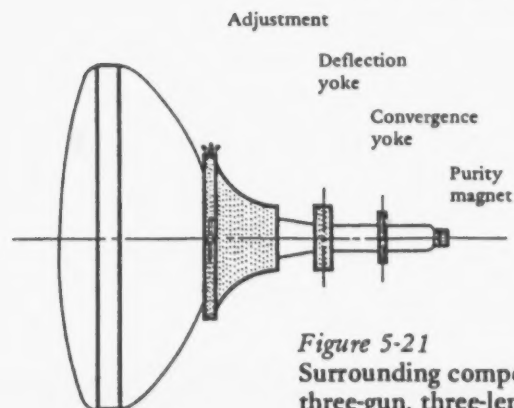


Figure 5-21
Surrounding components of the
three-gun, three-lens in-line colour CRT

The inner coil is the horizontal deflection coil, the outer coil is the vertical deflection coil.

The deflection coil used for the delta gun colour CRT is shown in Figure 5-22(a). The magnetic field produced by this coil is constant and the lines of flux are straight. This kind of magnetic field produces a distorted raster. The raster is pulled at the edges and compressed in the middle. This is pincushion distortion; therefore the pincushion circuit is used to get the proper rectangular raster.

For the in-line CRTs the magnetic field produced by the horizontal deflection coil is spool-shaped; the magnetic field produced by the vertical deflection coil is barrel-shaped, as shown in Figures 5-22(b) and 5-22(c), respectively. With these kinds of magnetic fields, the raster will be rectangular and the precision of the convergence improved.

Purity magnet. In colour CRTs the arrangement of the three electron guns is designed such that the three electron beams will converge at the centre of the shadow-mask hole. However, in actual instances the three electron beams do not always converge at the centre of the hole because of the slight misalignment of the electron guns. Thus a purity magnet is needed to adjust the path of the electron beams so that they will converge at the centre of the hole. The structure of the purity magnet is shown in Figure 5-23.

Convergence yoke. In colour CRTs the three electron beams must converge at the holes of the shadow mask and then hit their corresponding phosphor dots

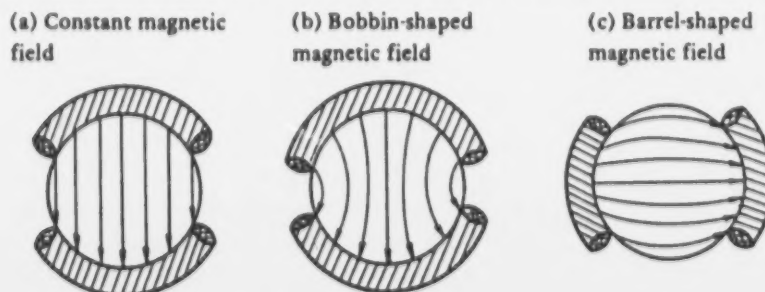


Figure 5-22
Magnetic field within a deflection coil

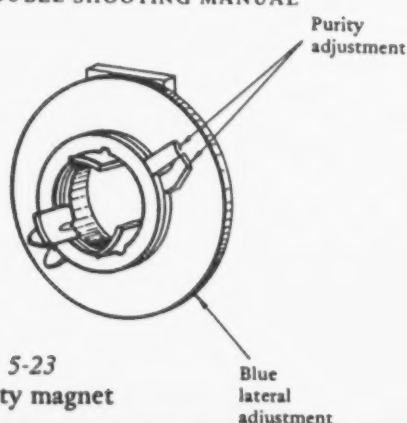


Figure 5-23
A purity magnet

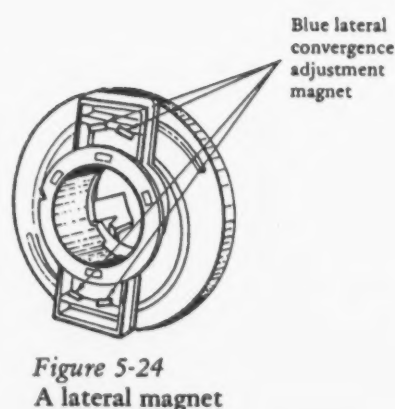


Figure 5-24
A lateral magnet

on the screen. If this happens, colour reproduction is properly done. However, if the three beams do not converge at the holes and do not hit their corresponding phosphor dots, colour fringing occurs.

There are two kinds of colour fringing. One is colour fringing all over the screen, the other is partial.

Colour fringing all over the screen happens when the three electron beams do not converge at the holes of the shadow mask and do not hit their respective phosphors. To eliminate this, the direction of each beam has to be precisely adjusted individually until the three beams converge at the holes of the shadow mask and hit their corresponding phosphors. This is like having three different bullets pass through one hole instantly but hit different targets. Figure 5-11 shows three different gun arrangements, with the three beams converging at a hole of the shadow mask and hitting only their corresponding phosphors. This adjustment of the directions of the electron beams is called *static convergence adjustment*.

A set of permanent magnets is used for static convergence to eliminate colour fringing all over the screen. Convergence coils are used for the dynamic convergence adjustment to eliminate partial colour fringing. The coils consist of the vertical and horizontal convergence coils. A current with a special waveform synchronising the current through the deflection coils is supplied to the convergence coils.

Lateral magnet. This magnet is used only for the lateral movement of the blue beam in delta gun CRTs. Because of the arrangement of the guns in delta gun CRTs, it is necessary to move the blue electron beam laterally for it to converge with the red and green beams. For this purpose, a lateral magnet shown in Figure 5-24 is attached between the purity magnet and the convergence yoke. This magnet is considered a part of static convergence adjustment. In some CRTs the positions of the purity magnet and the lateral magnet are interchanged.

Degaussing coil. The magnetic field of the earth is strong enough to magnetise the shadow mask. A magnetised shadow mask affects the direction of the electron beam. When the beam direction is affected, colour fringing occurs; therefore the shadow mask must be demagnetised. A degaussing coil mounted around the faceplate (see Figure 5-20) is used to demagnetise the shadow mask. The shadow mask is demagnetised by the decaying magnetic field produced by the decaying AC current supplied to the coil.

Convergence

As mentioned earlier, convergence is very important in colour CRTs. Besides the conventional types of CRTs, three major kinds of in-line CRTs have been developed. These CRTs are commonly used in modern TV receivers. The procedure for adjusting the convergence varies in different types of CRTs.

Delta gun CRT

Static convergence adjustment. By adjusting the permanent magnets of the static convergence adjustment shown in Figure 5-25(a), one changes the strength and direction of the magnetic field within the magnetic shield for each beam. The magnetic field will move the electron beams radially.

The displacement of the electron beams is proportional to the strength of the magnetic field. Figure 5-25(b) shows that the green and red beams will converge at a point. However, since the blue beam is displaced only radially, it has to be moved laterally to converge with the green and red beams. The blue beam is moved sideways by a lateral magnet. This adjustment of the blue beam is called the *lateral adjustment*.

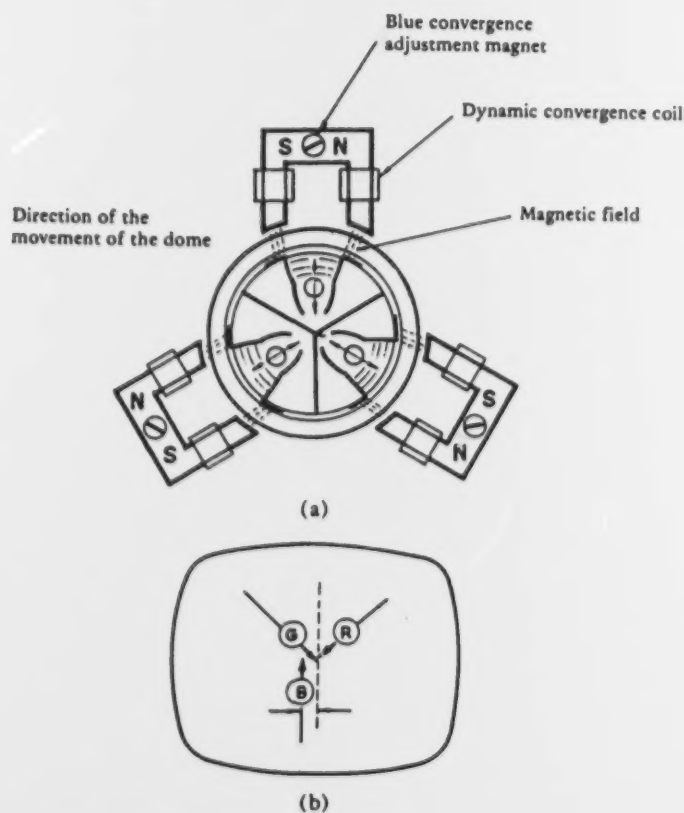


Figure 5-25
Components of static convergence
adjustment and static convergence adjustment

Dynamic convergence adjustment. As described before, adjusting the convergence of the beams on the centre of the screen is done by the static convergence adjustment. The dynamic convergence adjustment converges the beams at every hole of the shadow mask all over the screen.

Figure 5-26 shows the parts of the screen where the beams do not usually converge. The horizontal and vertical convergence circuits are designed to supply the horizontal and vertical dynamic convergence coils, respectively, with a parabolic sawtooth current. This current is taken from the deflection circuits and, after being processed by the convergence circuits, is supplied to the convergence coils. The current through the convergence coils will converge the beams all over the screen.

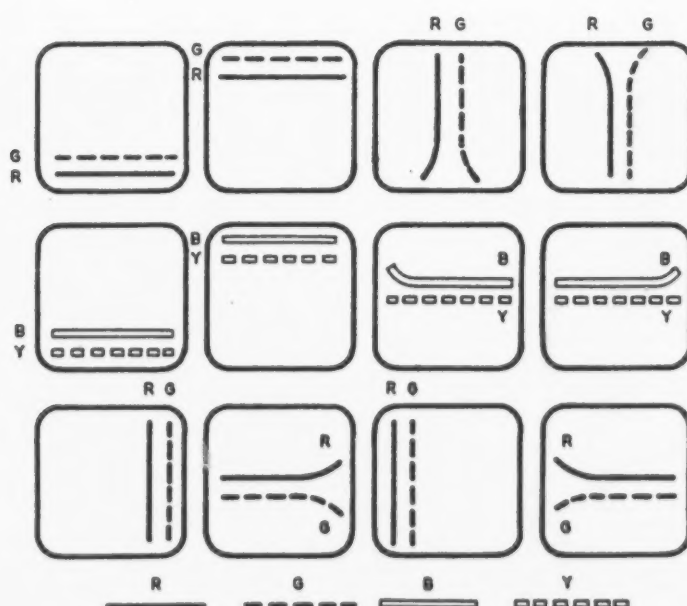


Figure 5-26
Typical poorly converged picture
(Y indicates yellow)

1) Vertical convergence circuit.

Figure 5-27 shows a vertical convergence circuit for the blue beam. The sawtooth voltage is tapped from the emitter of the vertical output transistor. This wave is integrated by VR1 and the blue convergence coil L; therefore a parabolic current will flow in L. On the other hand, a pulse voltage appears at the secondary winding of the vertical output transformer T during the retrace period. This voltage is integrated by VR2 and L; therefore a sawtooth current will flow in L. The resulting current that will flow through L is a mixture of a sawtooth and a parabolic current. The wave-form of the resulting current is shown in Figure 5-28. The convergence adjustment is done by varying the amplitude and the shape of the current through L by VR1 and VR2, respectively. The circuit and principle of the vertical dynamic convergence adjustment of the red and green beams are similar.

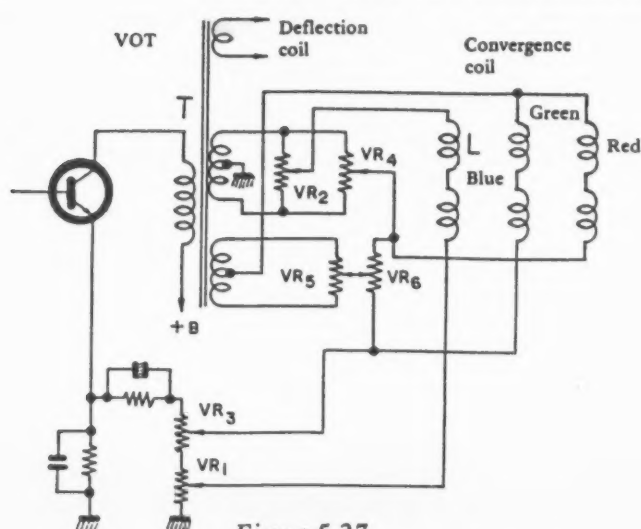


Figure 5-27
A vertical convergence circuit

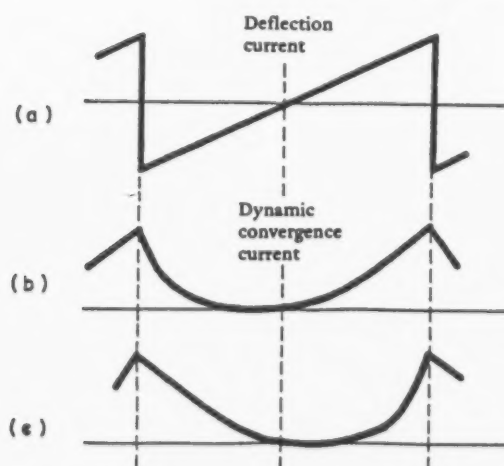


Figure 5-28
A parabolic current

2) Lateral convergence adjustment

Figure 5-29(a) shows a lateral convergence circuit, Figure 5-29(b) a blue lateral convergence circuit. The pulses from the horizontal deflection circuit are used as a power source.

The values of L_1 , C_1 and C_2 are designed such that the circuit resonates at around 15.75 kHz (horizontal oscillator frequency). When R_1 is set to minimum (0 ohm), a sinusoid-like wave-form with a 90-degree phase shift with respect to the input will appear between points (A) and (B). The current shown in Figure 5-30(a) will flow in coil L_2 .

When the value of R_1 increases, the quality factor Q between (A) and (B) decreases. With a high value of R_1 , C_2 is negligible. Thus the resulting current that will flow through L_2 will have a phase lead over the current that will flow through the coil when R_1 is minimum. See Figure 5-30(b).

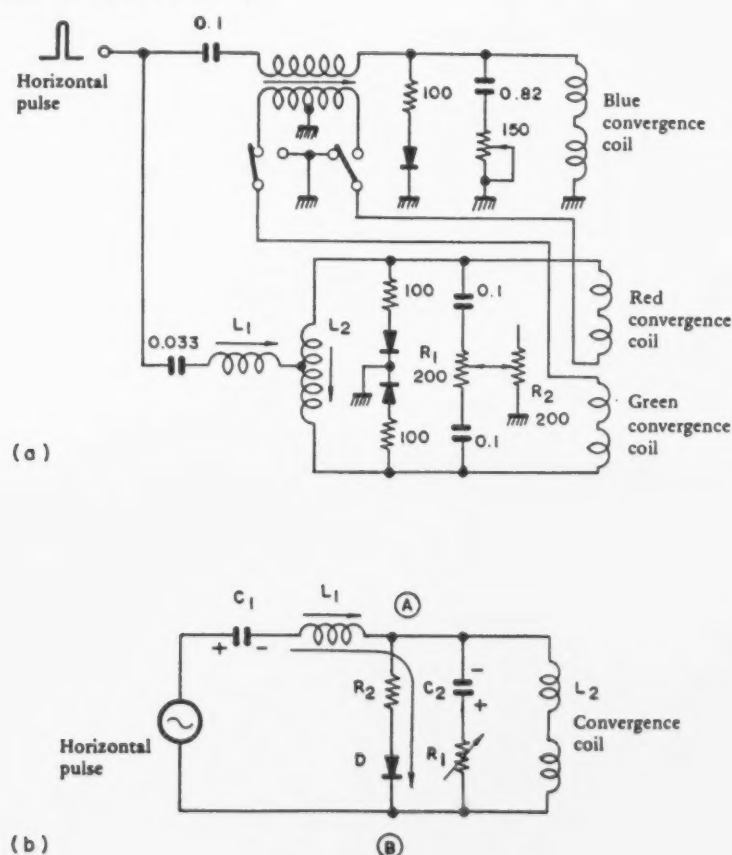


Figure 5-29
A horizontal convergence circuit

Lateral convergence adjustment is done by changing the phase and the amplitude of the current in L2. Variation in the current and resistance in L1 and R1 changes the current in L2.

In practical applications, the dynamic convergence adjustment for converging the beams at the centre of the screen is not needed. Therefore, R2 and D are connected in parallel to L2. When point (A) becomes positive with respect to point (B), diode D conducts, clipping the upper part of the sinusoid-like wave. Hence the current that will flow through L2 will be a parabolic current. Thus this lateral convergence adjustment circuit converges the beams at the right and left edges of the screen.

As shown by the wave-forms in Figure 5-30, varying the value of L1 while keeping R1 constant changes the shape of the wave-form more at the later part of the horizontal scanning period. Varying the value of R1 while keeping L1 constant changes the shape of the wave-forms more in the earlier part of the horizontal scanning period. Thus L1 is adjusted to converge the beams at the right edge of the screen; R1, to converge the beams at the left.

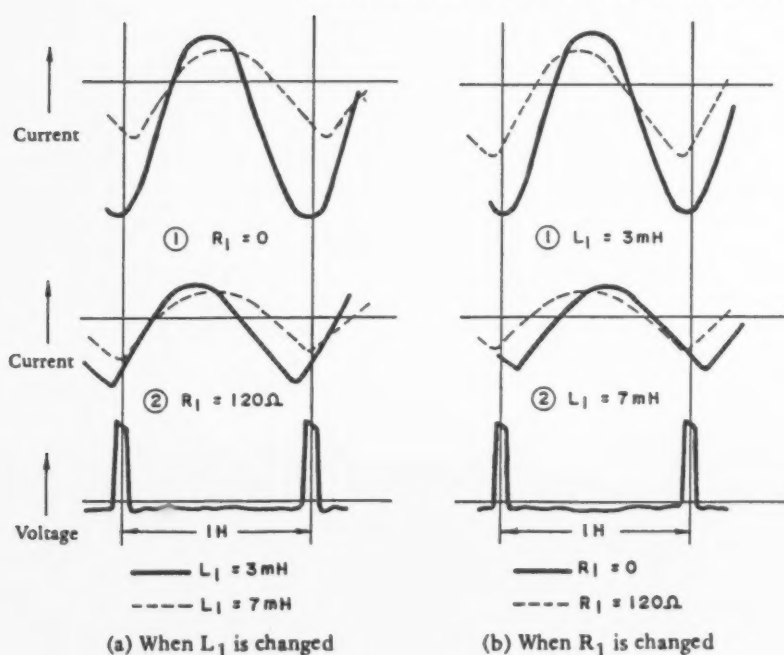


Figure 5-30
Current change in convergence coil
when the values of L_1 and R_1 are changed

In-line picture tube

The static and lateral dynamic convergence adjustments are needed for this kind of colour CRT.

Static convergence adjustment. In the in-line colour picture tube, the three electron guns are placed side by side forming a plane. The centre electron gun (green or red) is mechanically aligned with centre axis of the picture tube during manufacturing. For this kind of arrangement, convergence is needed only for the outer beams. Thus the structure of the convergence coils becomes simple. However, the vertical dynamic convergence adjustment and the static convergence adjustment can be omitted if a self-convergence deflection yoke is used.

In the three-lens in-line gun, an E-shaped convergence yoke is used. (See Figure 5-31.) Two permanent magnets mounted on each yoke can be rotated to displace the outer beams diagonally to converge the outer beams with the centre beam at the shadow mask.

Dynamic convergence. Using the self-converging deflection yoke in the three-gun, three-lens colour CRTs, only the horizontal dynamic convergence of the beams is affected. The vertical lines at the edges of the screen represent the symmetrical deviation of the green and red beams from the blue beam when the beams are deflected horizontally. The deviations of the outer beams increase as the beams are further deflected horizontally. The parallel vertical lines indicate that the direction of the beams with respect to each other is not affected when they are deflected vertically. Thus, only the horizontal or lateral dynamic convergence adjusted is needed.

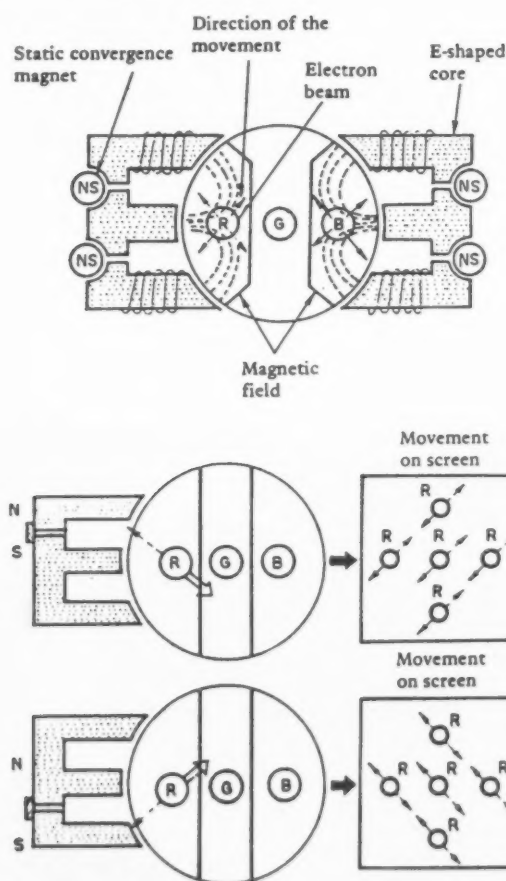


Figure 5-31
Convergence yoke and static convergence
of a three-gun, three-beam colour CRT

Figure 5-32(b) shows a lateral convergence adjustment circuit. The circuit for the red beam is symmetrical to the circuit for the blue beam. In this circuit a parabolic current with horizontal oscillator frequency flows through the convergence coils. The magnetic fields produced by the current flowing through the coils are controlled by VR and L_v to move the outer beams laterally. VR is adjusted to converge the beams at the left part of the screen; L_v to converge the beams at the right.

The convergence circuit for the one-gun, three-lens colour CRT is more complicated than that for the three-gun, three-lens colour CRT.

Self-converging picture tube. To make the self-convergence of the in-line colour CRT possible, one pays technical attention to the structure and magnetic field of the deflection yoke. The deflection yoke and the CRT are made as one piece.

- a The mutual guns are designed as close as possible.
- b The order of the setting of the phosphor screen is vertical-striped.
- c For dynamic convergence adjustment, a magnetic emphaser and shunt shown in Figure 5-33 are placed at the tip of the electron gun to emphasise and control

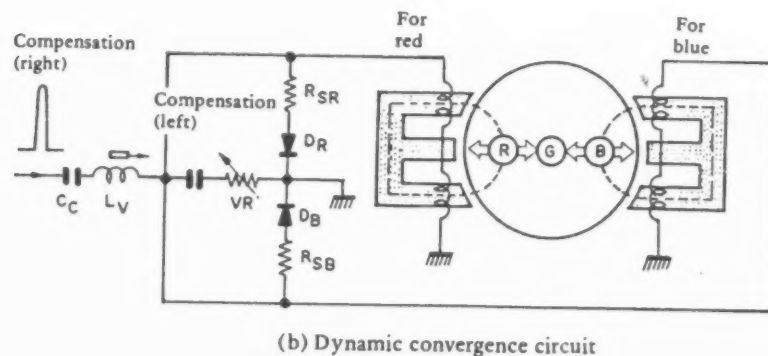
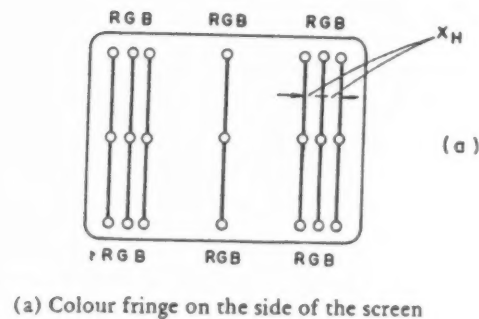


Figure 5-32
Functional circuit of dynamic convergence circuit

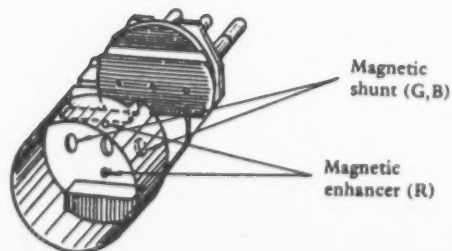


Figure 5-33
Component of magnetic field adjustment used in self-converging colour CRT

electron beam, respectively. The enhancer and shunt compensate for the different sizes of the raster made by the centre and outer beams.

a A specially designed deflection yoke is used to produce a barrel-shaped magnetic field for the vertical deflection and a spool-shaped magnetic field for the horizontal deflection.

Principle of self-convergence. The vertical self-converging deflection yoke is designed to produce a barrel-shaped magnetic field, as shown in Figure 5-34(a). The vertical component of the magnetic field where the B and G beams are located is opposite. Therefore, using Fleming's left-hand rule, the forces exerted by these components are opposite. The B beam will be moved to the left, the G beam to the right.

Structurally, the distance between the deflection centres of the beams and the phosphor screen becomes greater at the corners and edges of the picture screen than at the centre. Therefore, if an ordinary deflection yoke which produces a constant magnetic field is used, the deviation in beam landing will be greater at the edges. In the upper left edge of the screen, as shown in Figure (b), the G beam is deflected more than the R beam by the vertical component of the magnetic field, so that the G beam is driven farther to the left than the R beam.

On the other hand, in the B beam, the distance between the deflection centre and phosphor screen is smaller than the R beam. The B beam is not deflected sufficiently, thus landing on the right of the R beam on the screen.

To compensate for these deviations, the self-converging deflection yoke which produces a barrel-shaped magnetic field is used. The vertical component of this magnetic field will shift the G and B beams in opposite directions to make them land on the same point as the R beam.

On the other hand, the horizontal component of the barrel-shaped magnetic field is greater at the position where the B and G beams pass than at the position where the R beam passes. Therefore the vertical deflection of the

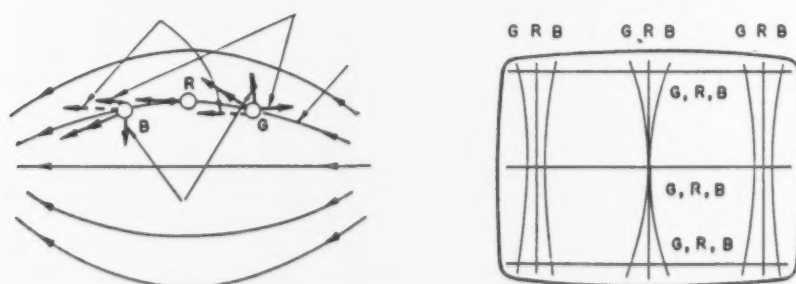


Figure 5-34
A barrel-shaped magnetic field

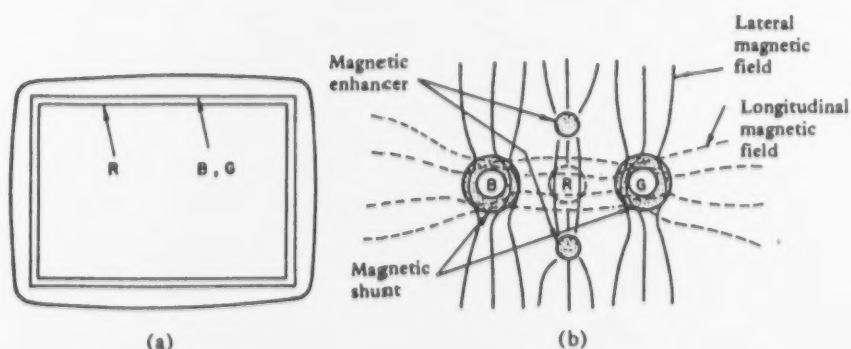


Figure 5-35
Magnetic enhancer for red beam and
magnetic shunt for green and blue beams

R beam is smaller than the B and G beams. Figure 5-34(a) shows three electron beams being deflected to the upper side of the screen. The same principles apply if the beams are deflected to the lower side. As shown in the Figure 5-35(a), the rasters produced by the B and G beams are exactly the same and the raster produced by the R beam is a little smaller. To compensate for the difference in raster size, a magnetic shunt is placed at the tip of the electron gun to reduce the strength of the barrel-shaped magnetic field on the B and G beams. The effect of the magnetic shunt is the same even in horizontal deflection.

If the horizontal deflection yoke is made to produce a spool-shaped magnetic field as shown in Figure 5-36(a), the vertical component of the magnetic field will be greater at the sides than at the centre. When the beams are deflected to the right, a stronger magnetic field will be acting on the G beam than on the B beam to compensate for the difference in the distance travelled by these beams. Hence the B and G beams will land on the same spot on the screen, as shown in Figure 5-36(b).

In the R beam the magnetic enhancer is used to enhance the centre magnetic field, causing a bigger deflection of the R beam. This will make the R beam land on the B and G beams exactly. In an actual self-converging colour CRT the structure of the electron guns and compensating magnets is designed to get the same result.

The magnetic enhancer for the R beam and the magnetic shunt for the B and G beams are located at the tip of the electron gun, as shown in Figure 5-33. The magnetic enhancer consists of two small metal pieces sandwiching the R beam; the magnetic shunt is a small cylindrical electrode where the B and G beams pass through. As shown in Figure 5-35(b), the shunt serves as a shield for the B and G beams against the magnetic field, so that the B and G beams will not be affected by the magnetic field when they travel through the shunt.

However, the unshielded position of the B and G beams will still be affected by the magnetic field. Nevertheless the net effect of the magnetic field on the B and G beams is reduced.

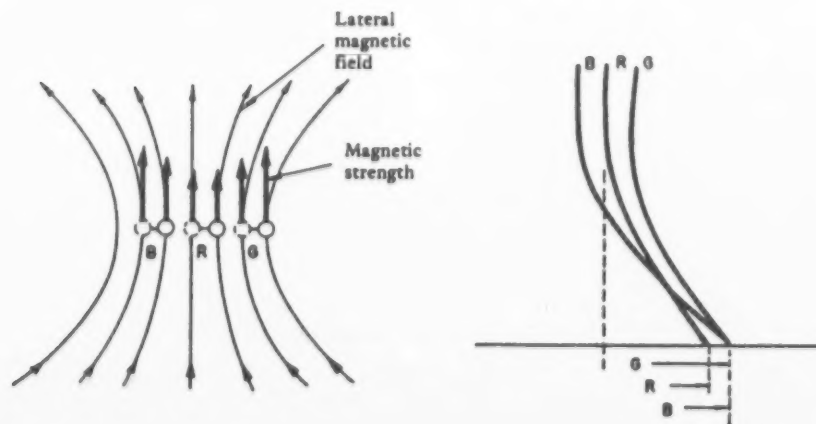


Figure 5-36
Spool-shaped magnetic field

The magnetic enhancer is small metal piece placed in the magnetic field to converge the horizontal magnetic field. Thus it produces a magnetic field which influences the R beam that passes nearby, enhancing the effect of the deflecting magnetic field on the R beam.

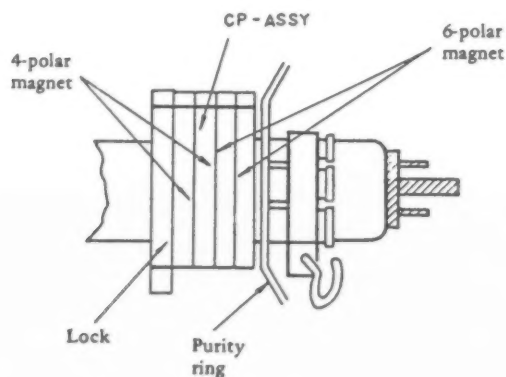


Figure 5-37
Components attached to the neck of a self-converging colour CRT

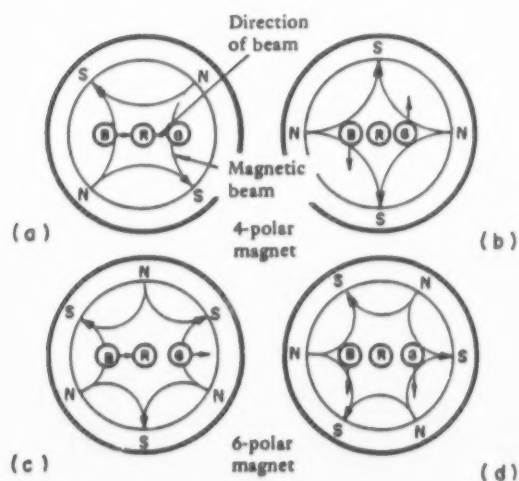


Figure 5-38
Four- and six-polar magnetic plates

Accessories of the self-converging CRT. The self-converging colour CRT requires the dynamic convergence adjustment but not the static convergence and purity adjustments. The assembly of magnets shown in Figure 5-37 is used for the self-converging colour CRT and constructed as one piece.

The purity magnet moves the three electron beams laterally so that they will meet with the axis of the tube.

For the static convergence adjustment, two pairs of magnetic plates are used. These consist of four- and six-polar magnets. The four-polar magnet displaces the B and G beams equally in opposite directions, as shown in Figures 5-38(a) and (b). The amount of displacement is varied by the angle of the plates, and the direction of the beams is controlled by the rotation of magnets. The six-polar magnet changes the direction and position of the B and G beams equally. Again, the rotation angle controls the amount of displacement and direction by the rotation of magnets.

Picture tube circuit

Brightness-control circuit

If the anode voltage is constant, the brightness of the picture tube depends on the amount of the electron beams hitting the screen. Therefore, by varying the bias voltage, the brightness of the screen can be changed.

Figure 5-39 shows the relationship between the brightness of the screen and instant grid voltage for different values of DC bias voltage. In (a) the DC bias voltage is so little that the screen still emits light even though the video signal has reached its black level. In (c) excessive DC bias voltage causes the screen to reproduce the grey and white levels of the video signal as black and grey, respectively. In both cases the correct brightness of the original picture is not properly reproduced. Figure 5-39(b) shows the proper DC bias. With a proper DC bias, the black level of the video signal coincides with the cut-off voltage of the CRT.

Present black-and-white TV receivers have no DC restoring circuit for the DC bias, and only the AC component of the video signal is coupled to the CRT.

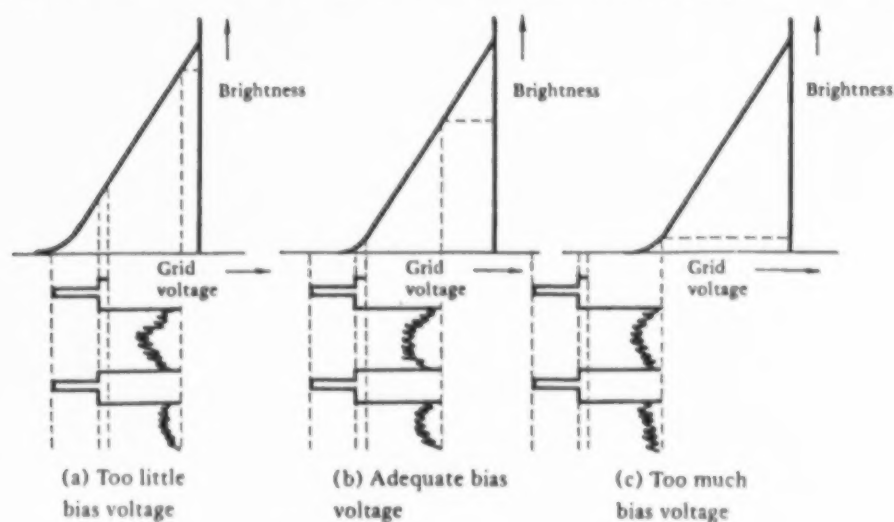


Figure 5-39
Grid voltage and brightness

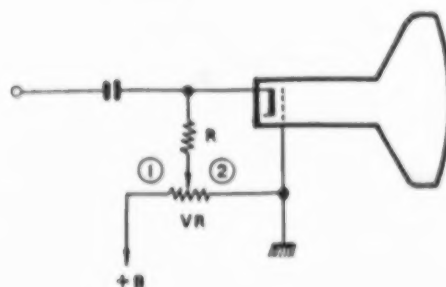


Figure 5-40
Principle of a brightness-control circuit

Thus a brightness-control circuit is used to adjust the average brightness of the screen. Figure 5-40 shows a brightness-control circuit in black-and-white TV receivers.

In colour TV receivers the brightness is controlled by adjusting the emitter voltage of the second, third or fourth video amplifier transistors. Figure 5-41 shows a brightness-control circuit in a colour TV. The emitter voltage of the fourth video amplifier is varied by adjusting the brightness-control potentiometer VR1. A decrease in the emitter voltage increases the collector current and reduces the collector voltage. Since the collector is directly coupled to the cathode of the CRT, the brightness of the screen will increase if VR1 is adjusted so that emitter voltage decreases.

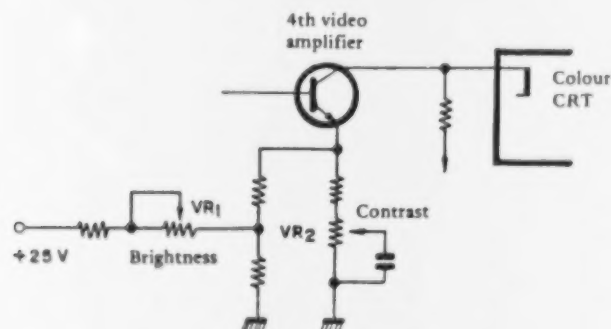


Figure 5-41
Brightness-control circuit of a colour CRT

White balance adjustment

A colour TV receiver should be able to reproduce a good quality monochrome picture when a black-and-white video signal is received. The electrode voltages and the drive voltage should be adjusted so that a good monochrome picture is reproduced. This is called the *white balance adjustment*. Poor white balance will cause the monochrome picture, particularly the bright parts, to have colours.

The light-emission efficiency of the three coloured phosphors should be the same for a proper white balance. However, because of the slight differences in the light-emission efficiency of the phosphors, the beam current ratio of the R, G and B beams is set to 34:34:32 to get a white balanced raster. A white balance adjustment circuit is shown in Figure 5-42(a). This circuit is used in colour TVs using the colour-subtraction drive system. The voltages of the three screen grids of the CRT are set to the cut-off voltage by adjusting a variable resistor for each grid. The drive-control circuit compensates for the differences in the characteristics of the three electron guns to produce the proper beam current ratio. Figure 5-42(a) shows G-drive and B-drive-control circuits. This kind of white balance adjustment circuit is commonly used in delta-gun and three-gun, three-lens in-line colour CRTs. The white balance adjustment circuit for the primary-colour drive output varies slightly among different CRTs.

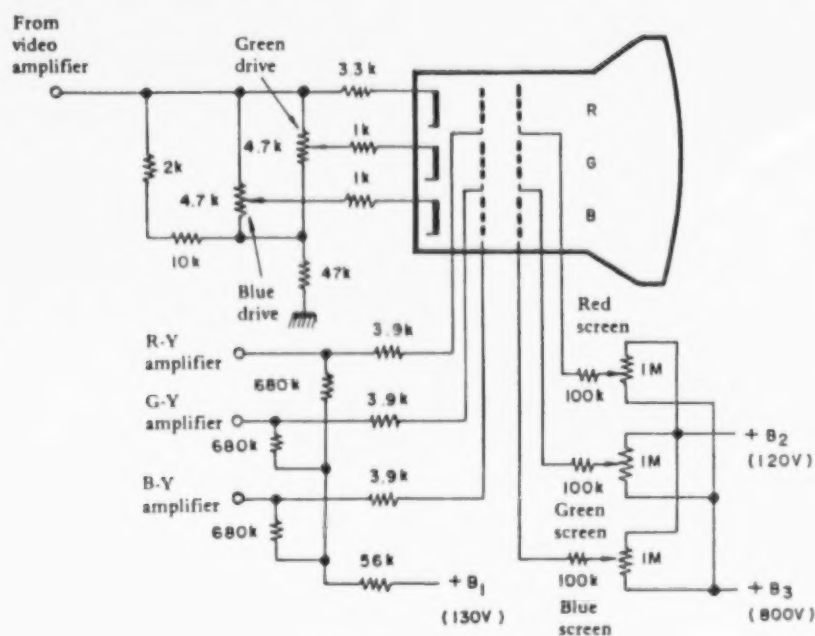


Figure 5-42(a)
White balance adjustment circuits and
colour-subtraction drive circuit

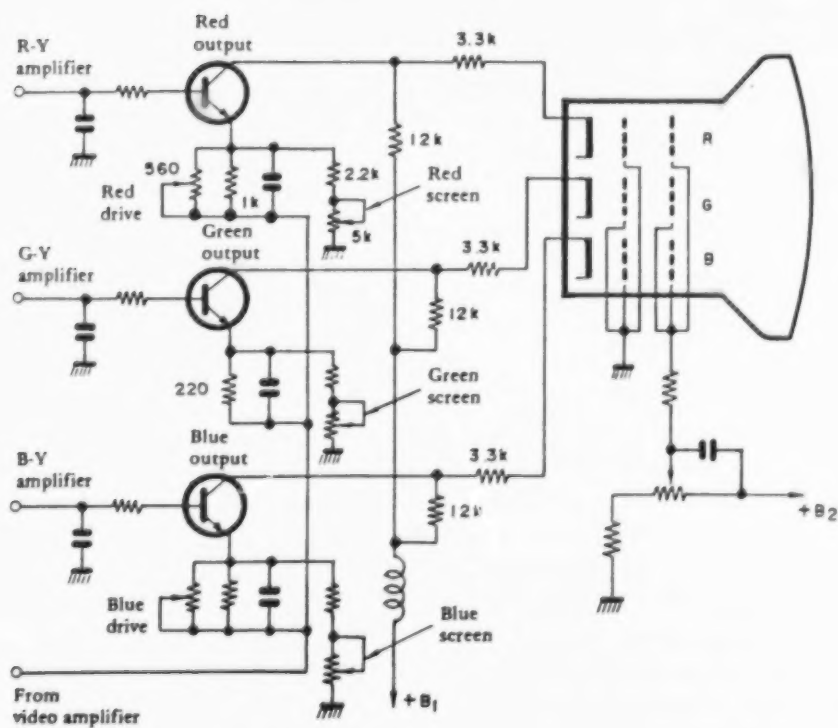


Figure 5-42(b)
White balance adjustment circuits and
primary-colour drive circuit

In in-line colour CRTs where the G1s and G2s are connected, voltages for each grid cannot be adjusted individually. The circuit shown in Figure 5-42(b) is used also in in-line CRTs where the three electron beams share the same lens. In this circuit the voltage of the screen grids is set to the cut-off voltage by adjusting a single variable resistor (BKG-VR). The ratio of the beam currents is adjusted by changing the amplitude of the Y signal applied to the emitter of the primary-colour output transistor. This amplitude is varied by adjusting the R- and B-drive controls.

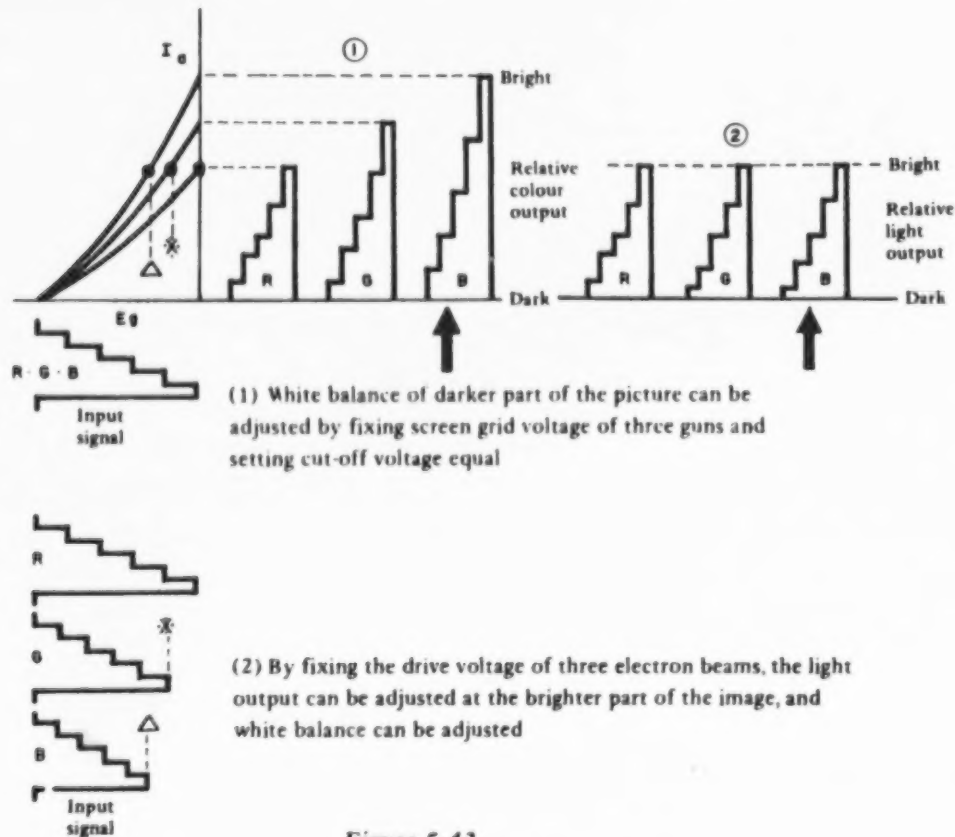


Figure 5-43
White balance of colour CRT

Focus circuit

To get sharp pictures on the screen, a focus voltage is applied to the focus grid. The electric field between the focus grid and the accelerator grid (anode) serves as a static lens that focuses each of the electron beams.

As discussed in the section on "General Characteristics of a CRT," focusing the electron beam by applying a focus voltage on the focus electrode is called *static focusing*. As mentioned before, there are two types of static focusing: uni-potential and bi-potential.

Uni-potential focusing. This type is commonly used in black-and-white CRTs and small colour CRTs. Figure 5-44(a) shows a circuit used for this kind of focusing. The focus voltage is taken from G2 and ranges from 0 to 400 V.

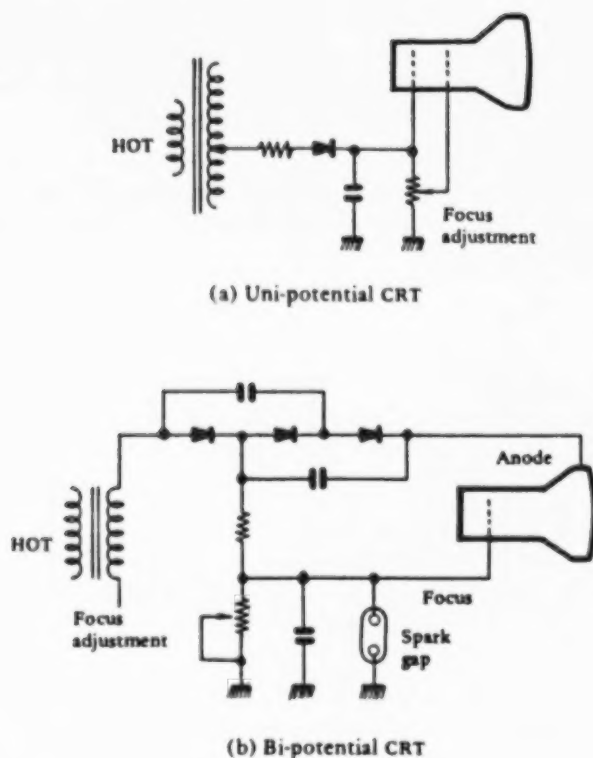


Figure 5-44
Focus circuits

Bi-potential type. The circuit for this type of focusing is shown in Figure 5-44(b). The voltage applied to the focus grid is taken from the high-voltage rectifier circuit. This voltage is usually around 20 per cent of the anode voltage.

Automatic digesting coil

As described in the section on "Basic Structure and Principles of the Colour Picture Tube," poor colour purity results when the shadow mask is magnetised. To demagnetise the shadow mask, a digesting coil is mounted around it. Automatic degaussing is done when the TV set is switched on. An AC current that gradually decreases in magnitude will produce a magnetic field around the shadow mask that demagnetises it. See Figure 5-45 for the wave-form of the applied current.

Several types of digesting circuits are used. Figure 5-46(a) shows one which uses a combination of a thermistor and a VDR (voltage-dependent resistor). When the power switch is turned on, the resistance of the thermistor is at first high because it is cold. On the other hand, the resistance of the VDR is low, the current flows through the digesting coil first. The temperature of the thermistor increases after some time, decreasing the resistance. Therefore current flowing in the thermistor increases. With a decrease in the resistance of the thermistor, the voltage across the VDR decreases by increasing its resistance.

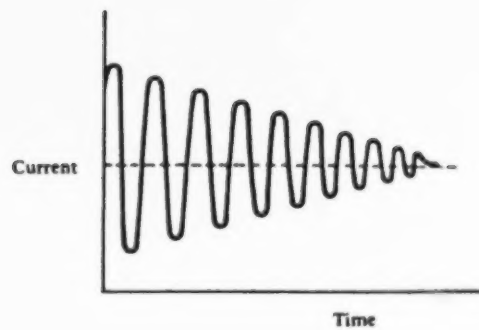


Figure 5-45
Ideal current flow in a degaussing coil

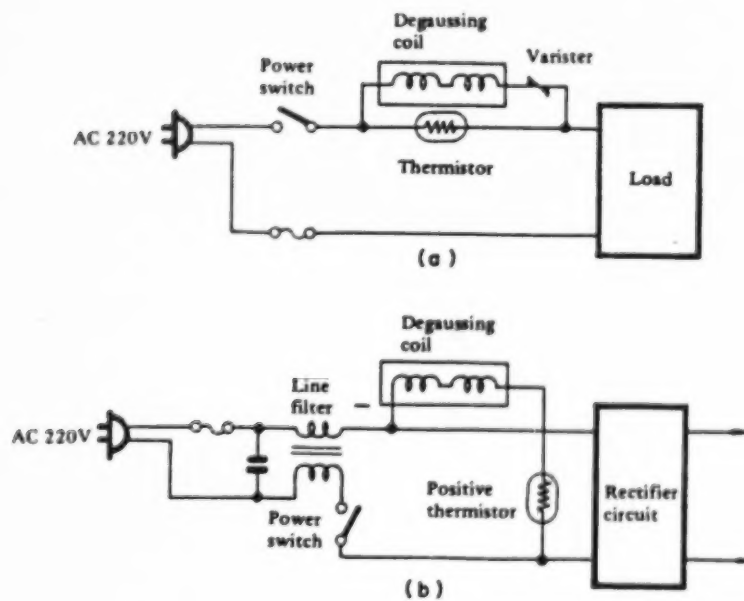


Figure 5-46
An automatic degaussing circuit



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